Heart rate as a game controller

Internship Report

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1.1 Introduction

A report from the World Health Organization from 2010 states that physical inactivity is now identified as the fourth leading risk factor for global mortality. This becomes more of an issue as levels of physical inactivity are on the rise in many countries, with many implications for non-communicable diseases such as cardiovascular disease, diabetes and overweight. Efforts to combat this are undertaken by both national and international organizations with many initiatives to promote exercise and awareness amongst the population. Numbers from the Dutch government show the amount of sedentary behavior amongst adolescents being one of highest due to many of the activities like gaming that involve a sitting or lying position.

Another concern is the decrease of exercise activities that are being undertaken with ageing and therefore the increased risk of an inactive older population. As populations have an increasing percentage of older adults with the percentage of the population being above the age of 65 projected at 16 percent in 2050. With increasing age, chronic conditions are more prevalent [1]. The process of degenerative loss of skeletal muscle mass quality, and strength associated with ageing called sarcopenia is only strengthened by the fact that the elderly are among the least physically active members of society. The decline of muscle mass in older adults leads to losses in functional capacity amounting to as much as 3 percent each year beyond the age of 60. The loss of muscle mass is not only an inconvenience or impeding in daily activities but is also clearly associated with health problems such as obesity, osteoporosis and type 2 diabetes [2]. Another problem associated with sarcopenia is the increased risk of falling, which in older adults often results in fractures. With reported fall rates of persons over 65 at 30 percent, and for persons over 80 years of age even higher at 50 percent, this can be seen as a major problem as falls amongst elderly people easily result in lasting injury and loss of mobility [3]. An American study states the importance of the goal of public health, especially among older adults. It further states the importance of older adults to retain basic mobility and the ability to perform daily activities, as the loss of these is linked to increased risk of illness, institutionalization, reductions in quality of life, and the increased risk of earlier death. It becomes clear that the need for exercise is not only there in the general population, but could result in especially great benefits for a population's older adults [3] [2].

1.2 Problem Definition

A growing trend in society is the rapid ageing of its population, especially in the developed world. One of the major accessories of this trend is the reduction in mobility and ability to perform basic tasks of older adults, causing an increase in their dependency on others, but also increases the risk of them developing medical complications. The effects of sarcopenia and the strengthening of this due to the lack of physical activity of older adults add not only to the risk of falls resulting in fractures, but also to the risk of developing further medical complications. A lack of physical activity among older adults and the effects of sarcopenia can lead to a vicious cycle, with an increasing decline of health as a result.

1.3 Cause-effect and goals schemes

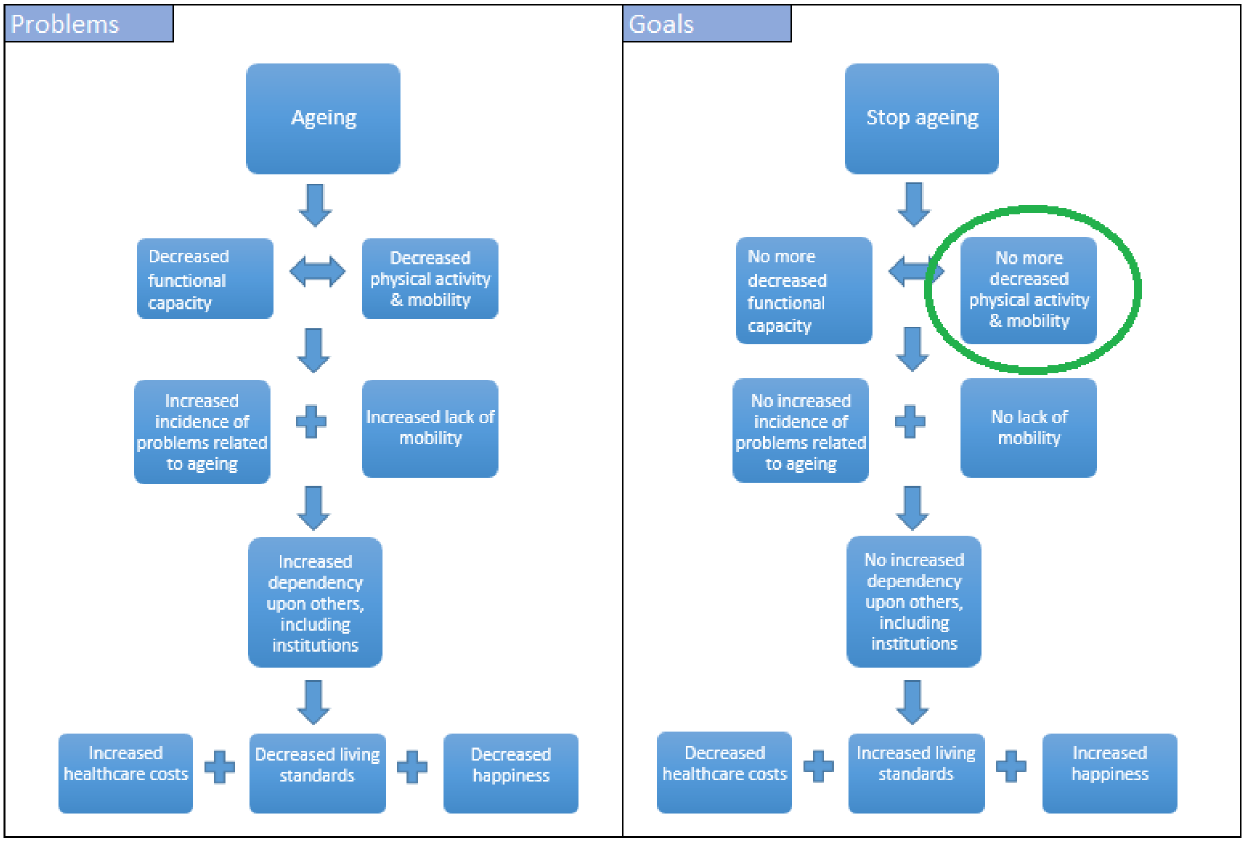

Figure 1 - Cause effect and Goals schemes

Seen above in the problems section of figure 1 is the cause and effect scheme of the general problem that is defined in section 2.2 (Problem definition). The main problem being ageing, which leads to a cascade of related problems. For each of these problems, a direct goal is envisioned in the goals section of figure 1 which would solve the related problem. As not all goals are realizable due to either the lack of expertise or other reasons, the highlighted goal has been chosen. For maximum effectiveness, the goal set to be achieved is always the highest achievable goal in the cascade. This will solve most of the related problems by cutting off the problem's cascade at the earliest possible point. [4]

2.4 Design Assignment

The goal set to achieve is to remove the lack of physical activity and lack of mobility suffered by older adults. This should be achieved by promoting physical activities in older adults. The strategy being to break the cycle of loss of muscle mass due to lack of physical activity which in turn adds to the loss of muscle mass.

Now the question becomes how the promotion of physical activity is best achieved given the tools and expertise at hand. The team which is tasked with realizing a solution consists of a game developer, an electronics and programming expert with an added focus on research into these fields and a biomedical engineer.

In light of this available expertise, the manner in which physical activity amongst older adults is promoted will be through the use of a game which motivates participants to become more physically active. The game should measure the performance of participants in combination with information about their health in an attempt to provide a more customized experience. [4]

2.5 Function Analysis

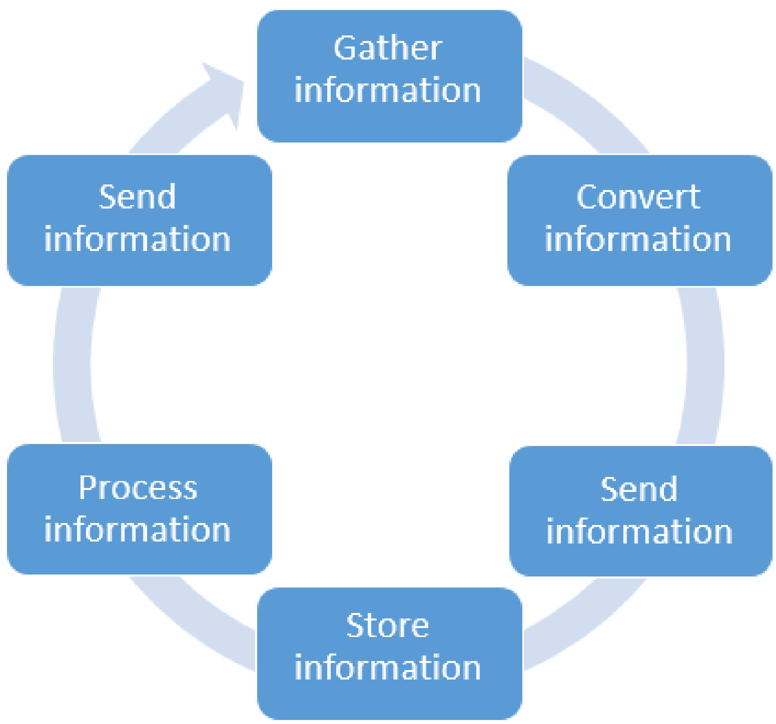

Figure 2 - Function analysis scheme

The functions of the game and surrounding components are to first measure activity information provided in some way by the participant, convert this to information which can be sent to a computer. The information will then be stored on the computer, the stored information will be processed and analyzed to analyze the participant's performance both during exercises and over the long term. The resulting feedback will then be relayed to the participant, after which a new cycle begins. [4]

2.6 Role demarcation

Within the process of developing a game, as there is in any multidisciplinary process, a division of roles is required. For the complete process of game content development, a division of roles could be:

- Animator (portrayal of movement and behavior within a game)
- Assistant producer (time and resource management within the development team)
- Audio Engineer (sound effects, music, voices and spoken instructions within a game)
- Creative director (responsible for the overall look and feel of a computer game)
- DevOps engineer (responsible for online infrastructure and security of web service)
- External producer (ensure successful delivery of a game)
- Game designer (devises how a game plays, defining all the core elements of the game)
- Game programmer (design and write the code that runs and controls a game)
- Game artist (creates the visual elements of the game)
- Lead artist (responsible for the overall look of the game)
- Lead programmer (responsible for creating all the game's code)
- Level editor (define and create interactive architecture for the game)
- Narrative copywriter (devises the narrative of the game)
- Product manager (help create and implement marketing campaigns)
- Project manager or producer (ensures the successful delivery of the game)
- Quality assurance tester (tests, tunes and debugs a game and suggests refinements)

However, a full staff is not available in this development process as the company and team developing the game is limited in size. As a result of this, most of the roles besides the core roles come under the company owner's responsibility. The three core roles that are present in the game design team are:

- Game designer (devises how a game plays, defining all the core elements of the game)
- Game programmer (design and write the code that runs and controls a game)
- Game artist (creates the visual elements of the game)

It is important to know where each of the team members are placed in terms of these core roles. The available team members are:

- A game developer
- An electronics and programming expert with an added focus on research in these fields
- A biomedical engineer.

The game developer will focus on the programming and the design of the game, the electronics and programming expert, who is also the company owner and project manager, will focus on all three core roles. The role of the biomedical engineer is not immediately apparent. To define where in the game development process the expertise of a biomedical engineer can best be put to use, a closer look will be taken at a simple game development branch structure. [5] [6]

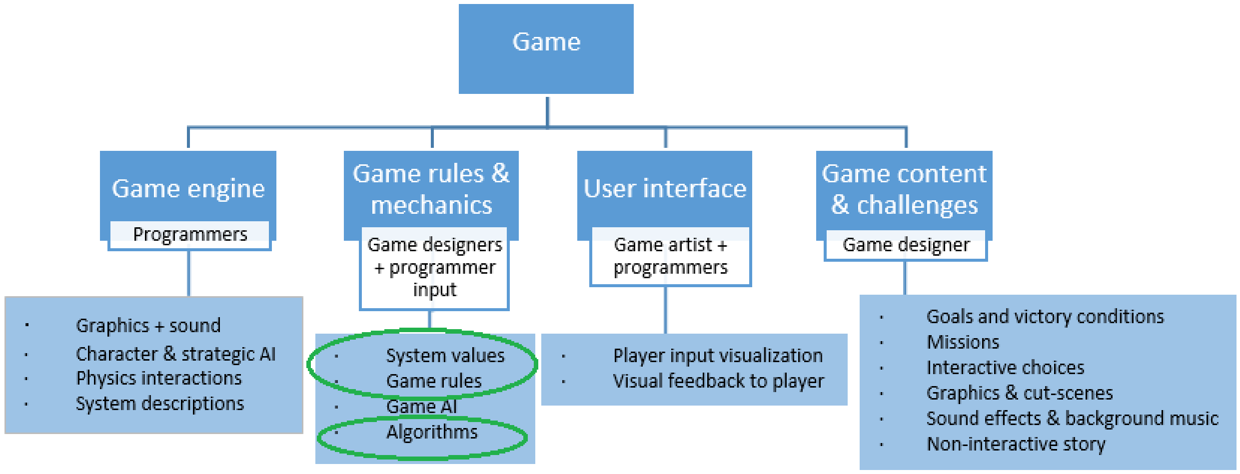

Figure 3 - Game components layout and Biomedical engineer role demarcation

The goal of a biomedical engineer is to form a bridge between the various technical and medical fields within a project. Looking at the game design component scheme above, a biomedical engineer can contribute to the devising of an algorithm and determining system values and game rules. The focus will be to devise these aspects of the game based on proper medical knowledge gained through interviews and a literature review. This means the biomedical engineer will be taking the role of a game designer. As the contributions to the project determine a major part of the game mechanics, close cooperation with the programmer as well as the project manager is required. Also, as medical expertise is partially lacking, the biomedical engineer will attempt to gather external expertise through the use of the previously mentioned literature review and interviews with medical experts. [7] [8]

2 Project

The project report will begin with a description of the project which is already running and the project's origin, followed by this report's scope within the game development. The main problem will be determined and broken down in the form of questions to be answered, followed by the documentation of the methods employed to answer these questions. Choices made and methods developed during the course of the project will be discussed. The chapter after game development will be dedicated to the experiment performed to test the developed software and hardware.

2.1 Project origin and description

Geedesign and Studio bleep, two of the companies that are part of the game company community called, are related to this project. The project itself started with the participation of the companies in a game jam (an event lasting several days in which several companies compete in creating the best game for a specific purpose) intended to develop a game for use in a pool. Winning this event with a game called "Kweekvijver", an idea emerged to create a gaming platform for use in swimming pools. This platform, called "Gamepond", was intended to use the physical movement of the people participating as controls for various games, similar to the function of the Wii. One of the games that is developed for this platform is the game "Aquatag". This game encourages participants to swim from point to point by having the game dictate which of several stations placed along the sides of the pool they have to reach and touch with an RFID tag to let the game know they have arrived. One of the intended target groups for this project were older adults. In search of clients and financing for the platform's further development, contact with the healthy aging project from the University Medical Center Groningen and the Rijksuniversiteit Groningen was made. Through them, a group of older adults from the Beatrixoord, a rehabilitation center in the village of Haren was envisioned as a target group for testing of the platform. With this target group came the realization that some type of monitoring of activity was desired in order to limit the activity level that would be set during the game. The use of biomedical engineering comes into play here, as it connects both the medical knowledge required to monitor activity and health and the technical knowledge to be able to communicate this to the other team members, who have a purely technical background. [9]

2.2 Scope of the report

The scope of the report will be limited to the work done by the biomedical engineer during the project, with information from the rest of the project added where needed for a better understanding. The work to be done is partially as a game designer, concerned with the inner workings of the game and game rules. The other part is more oriented towards the technical side of the game. For the latter part, examining the most suitable method of measurement and devices to measure with falls within the scope of the project, the data transmission, reception and storage does not. The method in which the data is analyzed does fall within the scope of this project, as this is paramount to the manner in which the game will function. Another reason why the data analysis falls within the scope of this report is that the method used to analyze the data, as well as the nature of the data that is collected, will be used to determine a measure of exercise intensity or performance. Therefore, this falls under the medical aspects of the work. Electronics issues, game graphics, signal analysis and most of the programming will fall outside of the scope of this report. The only programming to be discussed is the programming of the medical data analysis.

2.3 Problem definition

The main problem that is faced in this particular project is how to create a personalized gaming experience based on an individual's short and long term performance? This problem can be split up in three different components:

1. How can physical performance be directly and continuously measured?
2. How is the initial physical health state and improvement of physical health determined?
3. How can these values (performance and physical health) be combined into a representative and medically sound score within the game?

The answers to these questions will be regarded as the design assignments.

2.4 Design assignment 1:

How can performance be (directly and continuously) measured?

In order to properly measure a person's physical activity, quantification of activity is required. As there are many different parameters that can be measured, a selection will be made. This selection will be based on the degree to which a particular parameter or measurement is perceived to fulfill certain requirements. The requirements are also scored on their importance through weight factors as some requirements are more important than others. Finally, a score is assigned to each parameter or measurement, those with the highest scores will be taken into consideration for use. The green encircled scores in table 1 indicate the highest scores. For this reason, the data collection will be based on one these parameters or measurements.

2.4.1 List of measurement parameter requirements

There are a lot of methods of measuring activity of a person, however, we are looking for methods that are compliant with a specific set of requirements shown below. These requirements will be used in order to answer the first problem component: *How can performance be directly and continuously measured?*

- Accuracy – determined by the systemic error in the measurements

Not only is accuracy important from a quantification perspective, it is also connected to safety in cases where vital functions are measured. For this reason it is given a relatively high weight factor.

- Precision – determined by the range of random measurement errors, also statistical variability

Precision is given an average score, it is important for quantification purposes, but as measurements will be processed after collection, the lack of precision can be somewhat compensated.

- Representability – is the measured quantity correlated to the actual physical strain?

As this requirement is related to both safety and system quality, it has been given the highest weight factor.

- Reliability – the stability of the information stream

Reliability of the measurements is deemed very important, not only because of the potential of the game becoming a consumer product but also because of feedback reliability. Large gaps in data collection will be detrimental to the reliability of the game's feedback in both the short and the long term.

- Cost – of measurement devices, analysis and use

During the prototype phase, but especially when used as a consumer product, cost is imperative to the acceptability of the game. Given the wide range of prices for different types of measurements, it is very important to take costs into consideration.

- Data collection & processing -

The ability to collect the data that is measured is naturally very important. The ease of processing this data is also important, but mostly during the development stage. When a proper manner of data processing and analyzing has been developed, it will no longer be a factor of negative influence.

- Ease of use – the effort and amount of time investment needed in order to use to the product/method

A game, as a consumer product, should be very easy to use. Having the user perform a lot of, or difficult tasks in order to use the product will be very detrimental to the products success.

- Ease of implementation – the amount of time and effort to make the method work as intended

Although this is an important part of game development, like data processing it represents a difficulty during game development. Once the problems related to implementation have been solved, the problem disappears.

2.4.2 Measurement parameter selection

A preselection of measurement parameters has been made based on the available medical knowledge and relevant literature. These measurement parameters are selected based on their ability to represent a person's exercise status at any particular moment during the game.

	Accuracy	Precision	Representability	Reliability	Cost	Data collection & use	Ease of use (participant)	Ease of use (monitor)	Score
Weight factor	4	3	5	5	4	4	5	3	
Heart rate	7	8	6	6	5	6	8	5	26
Blood pressure	5	5	6	6	3	4	6	5	21
Steps taken	5	3	4	7	9	4	9	9	26
Oxygen saturation	7	7	2	6	2	2	3	5	17
Accelerometer	4	3	6	4	2	2	8	1	17
Self reporting	2	2	8	2	9	8	6	6	23
Doubly labeled water	8	7	8	8	2	2	3	2	21
Indirect calorimetry	7	7	7	7	3	4	2	3	21
Perspiration (skin conductance)	3	3	3	3	2	4	3	2	12

Table 1 - Measurement parameter scoring on the various parameter requirements

Heart rate

Measuring heart rate will allow for an indication of the physical exertion a person is experiencing. There are several methods of measuring a person's heart rate. One of these methods will be employed.

Electrocardiography

This technique is mainly used in clinical environments. It provides a detailed visualization of the cardiac rhythm. Several leads are placed on the human body, the standard positions are the left arm, right arm and left leg. The heart rhythm is determined by determining the time between the R-peaks in the picture available below which represents the electrical activity of the heart during a multiple heart beats. Although it is the most accurate method of measuring heart rate, it will not be fit for the intended use of this project. It is not user friendly due to the expertise the implementation requires, the wires required during measurements will be cumbersome when moving and use in water is not possible. [10]

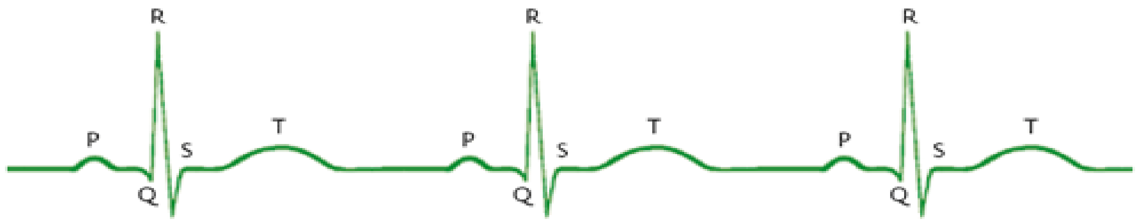

Figure 4 – Schematic representation of PQRST waves (hartwijzer.nl)

Pulse oximetry
This technique allows for the measurement of the oxygen saturation by color measurements, approximations of the blood pressure and measurements of the heart rate. The heart rate measurements are based on the time between oxygen level peaks. The need for constant wearing of the device will, much like the use of an electrocardiogram, be cumbersome. The inaccuracy of commercially available pulse oximeters is another reason for not employing this technique. [10]

Figure 5 - Pulse oximeter (https://upload.wikimedia.org/wikipedia/commons/7/7d/Wrist-oximeter.jpg)

Heart rate monitors
Heart rate monitors are widely used in sports in order to measure performance. These devices come as either a chest strap with a wrist receiver or as a wrist band itself. The monitors either have conductive smart fabric acting as electrodes with built-in microprocessors that analyze the electrocardiogram signal or by emitting infrared light and subsequently measuring the transmittance of this light. The heart rate is then determined as the time between peaks in absorbance of the infrared light due to the increased blood flow at moments when the heart beats. Although the accuracy of these devices are not yet proven to be of medical grade, the ease of use and continuous nature of measurements, as well as the possible availability of measurements in water makes this a promising technique for measuring physical activity. [10]

Steps taken (Pedometer)
Modern pedometers work by recording patterns in motion through accelerometers. Although there are clear accuracy limitations in measuring physical activity when using pedometers, they can provide a sufficient estimate of a person's activity and change in activity during a period of days or weeks. [11] [12] [13]

Self-reporting
The last method of measurements is the least accurate and least quantitative of the three measurement techniques. However, self-reporting can provide an insight in perceived intensity of exercises and questionnaires are often used as a tool for assessing rough physical activity levels, self-reliance and independence. Although it might be difficult to implement in game, it will still be a useful side tool for supporting personnel. [14]

Borg scale

The Borg scale is a subjective measurement of a load or exertion experienced by a person. As seen on the figure to the right, a person can classify their exertion level according to the scale provided. Often used in conjunction with heart rate monitoring, the Borg scale can be used to provide an estimate of exercise intensity. Physiotherapists especially use this test in order to assess the intensity of an exercise as perceived by the patient. If implemented properly, perhaps this test can be employed by the game to provide a more detailed picture of personal heart rate scaling. [14]

Rating of Perceived Exertion Borg RPE Scale

6		How you feel when lying in bed or sitting in a chair relaxed. Little or no effort.
7	Very, very light	
8		
9	Very light	
10		
11	Fairly light	
12		Target range: How you should feel with exercise or activity.
13	Somewhat hard	
14		
15	Hard	
16		
17	Very hard	How you felt with the hardest work you have ever done.
18		
19	Very, very hard	
20	Maximum exertion	Don't work this hard!

Figure 6 - Borg scale (excarbs.com)

2.4.3 Measurement device selection

As reliability largely rests on the actual wearing of the measurement devices by the participants, the decision has been made for a heart rate monitor and pedometer in one device. Price, available functions, size and weight, battery life and use under water will be the most important factors in deciding which devices will be used. Due to price limitations, devices over 250 euros have not been considered for the product review.

Wristbands & Watches	Price (in Euros)	Bluetooth	Weight (grams)	Water proof	GPS	Pedometer	Battery life	Temperature gauge
Xiaomi Mi band Smart Armband Fitness	€ 46.00	Yes (4.0)	20	No	Yes	Yes	6 days	No
F68 Smartwatch	€ 70.00	Yes	100	Yes	No	Yes	7 days	Yes
MIO VELO HR BLUE	€ 100.00	Yes (4.0)	N/A	Yes (30m)	No	No		No
Scosche Rhythm+ Heart Rate Monitor Armband	€ 70.00	Yes	N/A	Yes (1m)	No	No	8 hours	No
TomTom Spark	€ 150.00	Yes	50	Yes (50m)	Yes	Yes	336 hours	No
Fitbit surge Fitness superwatch	€ 230.00	Yes	N/A	No	Yes	Yes	120 hours	No
Garmin vivofit	€ 100.00	Yes	30	Yes (50)	No	Yes	8766 hours	No
Timex Ironman	€ 100.00	Yes (4.0)	N/A	No	No	Yes	168 hours	No
Polar FT4 heart rate monitor	€ 60.00		N/A	Yes (30m)	No	No	N/A	No
Mio alpha	€ 160.00	Yes (4.0)	N/A	s	No	No	10 hours	No
Mio Fuse	€ 140.00	Yes (4.0)	N/A	No	No	Yes	N/A	No
Sony Smartband 2	€ 150.00	Yes (4.0)	20	Yes (1.5m)	No	Yes	72 hours	No
Withings Pulse O2	€ 90.00	Yes (4.0)	8	No	No	No	336 hours	No
Chest straps								
Polar H7 Bluetooth Smart Heart Rate Sensor	€ 55.00	Yes	N/A	No	No	No		Yes
WAHOO TICKR /sportband	€ 50.00	Yes	N/A	Yes/1.5 meter	No	No	354 days	Yes
Runtastic Bluetooth Smart Combo Heart Rate Monitor	€ 55.00	Yes	N/A	No	No	No	N/A	No
HRM-Tri™ /sportband	€ 130.00	Yes (4.0)	59	yes (50m)	No	No	10 months	No
Suunto Smart Sensor	€ 80.00	Yes (4.0)	N/A	Yes (30m)	No	No	500 hours	No

Table 2 - Review of heart rate monitors

After compiling the list seen above, the choice for heart rate monitor was made based on the available functions, their price relative to the other devices and the number of times they were mentioned positively in reviews. The Mio Fuse was eventually chosen as the most suitable heart rate monitor. Although not immediately suited for use in water, it seemed the best option. It will be later assessed in a small experiment, should the Mio Fuse not be deemed suitable for use based on this experiment, the choice will be reevaluated.

Bluetooth Low Energy and ANT+

With the use of the Mio Fuse heart rate monitor, two Bluetooth protocols are available. Bluetooth Low Energy (or BLE), which is much more widely used across multiple platforms for a wide range of views and ANT+, which is mostly used in fitness equipment and has a well-established interface for heart rate monitors. The choice for the use of either protocol will be based upon the results of the experiment which will be done at a later stage of the project. [15]

2.5 Design assignment 2:

How is the initial physical fitness and improvement of physical fitness determined?

A person's physical health can be accurately determined using standard tests performed by medical experts such as physical therapists and through available medical background information.

When assessing a person's health before using a game which will potentially involve a wide range of physical fitness states, it is important to avoid floor effects (when the lowest score available is too high for some participants) and ceiling effects (when the highest score available is too low for some participants). Therefore, it is preferential to have multiple tests to asses a person's health state from a broad spectrum of available health states. An especially useful guide for a rough classification is the care profiles determined in the care module activities provided by the Royal Dutch Society for Physiotherapy (KNGF) [16]. These profiles range from healthy individuals who are able to engage in individual activities outside of the care system to individuals who require personal guidance in physical activities by specialized personnel. Placement in these categories is based on several tests performed by physiotherapists including the six minute walk test and the Åstrand test as well as known pathologies, chronic conditions and other medical background (see Appendix 2). Personal motivation and aim of the participant are also taken into account during placement. As they are parts of an official guideline, these profiles should be used in order to classify participants of the game whenever they are available. It is important that these profiles should only be determined by medical experts as they require appropriate medical knowledge to establish. The use of these profiles is therefore limited and dependent on the availability of these medical experts.

Worth noting is that the differentiation of individuals through these tests will result in a very large portion of participants being classified under the healthiest category when regarding an average population of people. Therefore, performance of an activity suitable for this category allows for further differentiation by using the heart rate measurements and Borg scale assessments to vary exercise intensity levels.

The progress of a person's physical health state can be determined by repeating the same tests used by medical experts in order to establish the initial profile. However, a game participant will indicate their perceived exertion through use of the Borg scale during the game. This can be used in combination with knowledge of previous exercise levels and related Borg values to assess a person's change in physical fitness. Pedometer measurements can provide illustrations of a person's global progress in ambient activity levels. The game should respond to these increases in physical fitness and activity by providing positive feedback. The manner in which this feedback will be delivered is beyond the scope of this report.

The protocols of the set of discussed tests will be added in appendix 2.

2.6 Design assignment 3:

How can these values (performance and physical health) be combined into a representative and medically sound score within the game?

Performance can be measured through the use of heart rate and the Borg scale during exercise. Heart rate measurements will be implemented into an algorithm that uses the Karvonen formula and the provided information to establish a rough estimation of person's maximum heart rate [17]. Through the use of the continuous heart rate measurements and the Borg scale the algorithm adapts the intensity levels according to perceived exertion for further detailing. Within the game, there should be an arbitrary score that determines the level of physical exercise that is performed, by increasing or decreasing time given to complete a task, decrease or increase repetitions of a task or similar methods. A participant being below, above or at their intended intensity level should cause this score to be adjusted accordingly.

Although the final programming of the game is done in the Unity engine, the module that is responsible for the heart rate calculations and adaptations can be created using Matlab. This module will later be translated to the C sharp programming language in order to allow the module's use in the Unity engine. The actual script, along with a written explanation will be added as Appendix 1.1 at the end of this report. For a clearer and simpler overview of the script, a flow chart will be added on the next page instead.

Note in this flow chart that the random values created in the third green calculations box are created in order to simulate the incoming heart rate and Borg values in Matlab. Naturally, in the actual game, these values will be provided by the heart rate monitor and participant's own indicated Borg values.

Finally, multiple additions to this particular script have been made, but have not been implemented in the full program yet and therefore will not be tested either. However, their workings are explained in Appendix 1.2, for the addition for tracking steps taken, and in Appendix 1.3 for the addition for monitoring heart rate stability and exercise intensity changes.

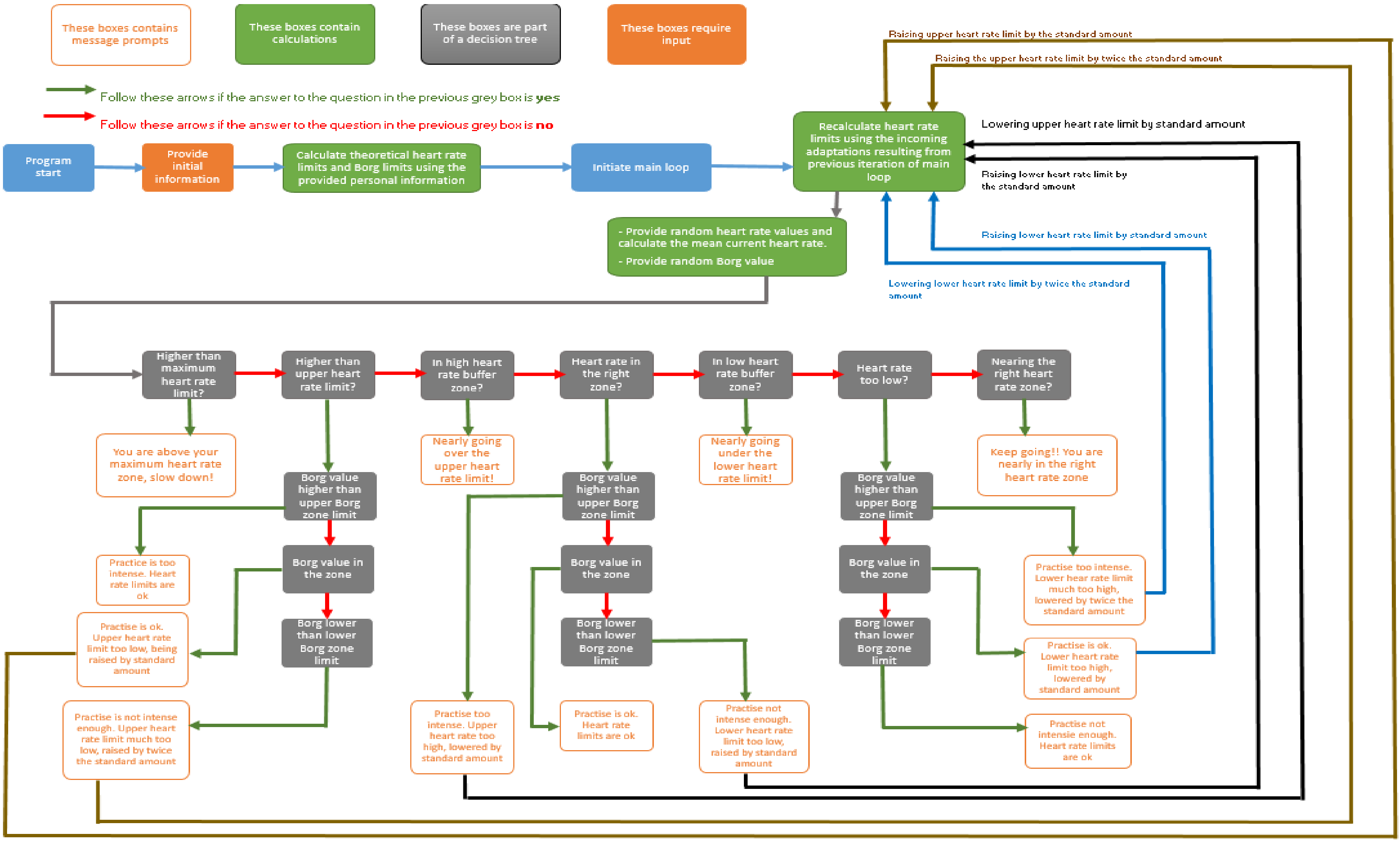

Figure 7 - Flowchart of heart rate analysis module

3 Experiments

In order to check the proper workings of the both hardware and software components, an experiment will be set up. Hardware components to be tested are the Bluetooth recording device and the data receiver device, which will be a tablet. Other hardware components to be tested are the stations at the sides of the swimming pool used for game related purposes. These will be tested for data reception and sending. The last hardware component to be tested is the Arduino-Android combination device that will receive and translate the incoming data from the stations previously mentioned.

Software components to be tested are the data collection and storage functionalities, the heart rate and heart rate zone determinations and calculations and the transfer of the collected data between components of the game.

3.1 Experiment components

Hardware – Bluetooth devices

It is possible for Bluetooth connection drop off as the Bluetooth recording device (the Bluetooth heart rate monitor) is below the water's surface, either in periodic fashion due to swimming movements or for an extended period when the device remains under water. Testing for this is very important, especially in the connectivity characteristics in the software to be written. The frequency at which the Bluetooth device transmits heart rate measurements should be high enough to provide real time heart rate samples during swimming. However, during stationary periods or other periods (or swimming styles) where the device will be submerged for longer time periods, the receiver should not turn off. This signal down time can be used to properly configure the software so the receiver will not turn off. Of course, the most important aspect of this test is to be able to solve further unforeseen complications of using a Bluetooth device while swimming.

The second part of the Bluetooth check is the receiving end of the hardware. For the Bluetooth heart rate monitor, the receiver is a tablet containing an application which processes the incoming data. The most important aspects to test this hardware component for is the proper reception of the incoming heart rate data.

Hardware – Stations on the sides of the pool & the Arduino-Android combination device

These stations have been developed in order to communicate the position of the game's participants in the pool using bracelets they wear. Because of the limited scope of this report, these will be discussed very briefly in the results.

The Arduino-Android device functions as the receiver for the positional information sent by the stations on the sides of the pool. In later development, the Arduino-Android combination is intended as the central reception device for all signals. However, due to software availability restrictions this is not possible at the time of the experiment. Specifically, Android 4.0 Icecream does not support Bluetooth Low Energy. Therefore, in the experiment, the previously mentioned tablet will be used for the Bluetooth heart rate monitor.

Software – Code verification

The testing of the software component which regulates the heart rate zone limits is paramount to the proper workings of the eventual game mechanics. The heart rate zone determinations have been written using Matlab. However, the Unity engine used for the coding of the game and the app created for the Bluetooth signal reception on the tablet cannot read the Matlab language. Therefore, the code written in Matlab is converted to the C sharp programming language. As a first version of the code which has also been translated, it is likely that mistakes have been made in the process. Testing of the system allows for the detection of these mistakes.

Software – Heart rate data storage and processing

In order to do long term analysis, it is imperative that the data will be stored properly. Due to connection related problems gaps in stored data can arise, which will provide problems with the reliability of data analysis. During the experiment, different exercise intensities will be simulated in rough forms, being slowly swimming for low intensity, up tempo swimming for middle intensity and swimming at maximum capacity for as long as is possible for very high intensity. At the transitions between these intensities, a notification will be made in the dataset to allow for a rough distinguishing between zones. For a better picture of what the heart rate range of a particular intensity zone is, the person is asked to remain at the same level of exercise for a couple of minutes. The experiment will also be done with at least one younger (19 years old) and one older person (58 years old), both healthy. This should allow for the comparison between ages at some level. After the experiment, the data will be analyzed to check for the validity of the devised heart rate analysis system. The aim of which is to devise quantitative and qualitative improvements to the system.

3.2 Experiment set-up

The experiment will be set up in a swimming pool in Niekerk. Before the actual swimming will begin, the distance between the heart rate monitor and the tablet at which the Bluetooth LE and the ANT+ signal will drop off will be determined for both in and out of the water. For more clarity, a sketch of the situation is depicted below. The stations which have to be tagged using the RFID tag will be placed along sides of the pool to allow for tracking if the number of lanes that have been completed. The stations will send the appropriate information through an XRF wireless connection to an Arduino-android computer which is stationed at the entrance to the pool. The heart rate monitor will be worn by the swimmer and a person will be at the side of the pool holding a tablet to keep an eye on the incoming data, as well as relay feedback to the person swimming on his or her performance, as this is not automated yet.

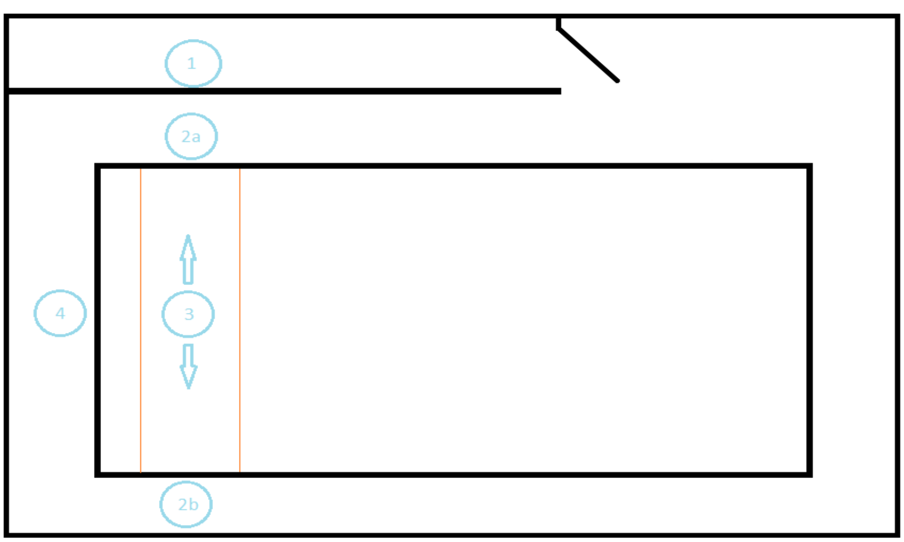

Figure 8 - Pool experiment set up.

1) ANT+ and XRF receivers.

2a & 2b) RFID stations.

3) Swimmer wearing heart rate monitor.

4) Tablet operator.

3.3 Experiment results

Hardware – Bluetooth devices & protocol usage

The tests proved the difficulty with Bluetooth signal reception when under water. During slow swimming or remaining stationary in the water with hands below the surface, the signal reception was non-existent. During quicker swimming, especially during maximum intensity front crawl, the signal reception became much better as the swimmers arms were under water for much shorter time periods. Noticeable differences in connection quality between the use of ANT+ or Bluetooth Low Energy (or BLE) came down mainly to a difference in range of reception, with the use of ANT+ having roughly half the range of the use of BLE. This range difference can partly be explained by the different use of tablets and the fact that the ANT+ device was being used from behind a window while the BLE device was being used from inside the pool area. Neither of the receivers (ANT+ and BLE) had signal sampling problems, as both signals were received as soon as the devices were out of the water. Neither receiver would turn itself off due to a lack of signal reception. Instead, both systems (an off the shelf system for ANT+ and the self-made heart rate analyzer for BLE) provided feedback when no signal was received.

Hardware – Stations on the sides of the pool & the Arduino-Android combination device

The stations on the sides of the pool worked properly as long as they were not placed under water. Similar to the Bluetooth devices, the signal from the stations was not received by the Arduino-Android device when the signal had to traverse through water. For future use of the Arduino-Android device, the implications remain the same for whichever signal used, the devices sending or receiving signals all have to be placed out of the water at times when data needs to be transmitted. A bigger problem concerning the stations is that they stopped responding completely after a certain time, regardless of distance to the receiver or whether it was in or outside of the water. The reasons, as well as the exact origin of this problem are yet to be determined.

Software – Code verification

During the tests in the swimming pool, no apparent mistakes in the programming were found. This is probably caused by the large amount of in office testing that was done. Simply having someone wear the heart rate monitoring device and testing the software's response to incoming measurements. The system responded to heart rate changes and further input of information as it should. Even the adaptations of the heart rate limits through the implementation of the Borg scale seemed to work as intended.

Software – Heart rate data storage and processing

Differences in training intensities were clearly visible in the heart rate graphs for both the stock heart rate analysis program and the self-made heart rate analysis program, differences between swimmers could not be determined. The major software issue discovered during these tests was the inability to access the database from the tablets using the available wireless internet connection. Although the connection to the internet was sufficient, the data base could not be accessed due to unknown reasons. This will need to be addressed during further development of the system.

Data results

The heart rates were measured with the same heart rate monitor device. Two different signal protocols have been used, ANT+ and BLE. Two tablets were used, one for ANT+ and one for BLE. For both signal protocols, a different application was used. For ANT+, a stock application was used, for BLE, the self-developed application was used. The ANT+ app measured the signal continuously, although the BLE application did the same, only screenshots of part of the measurements are available due to the previously mentioned database problems.

ANT+

The ANT+ screenshot is divided into three sections: a left, middle and right section. These sections correspond to the three different persons wearing the heart rate monitor. For the left section, a distinction can be made between slow swimming, indicated by the first part of the horizontal line and the number 1 in the image, and being out of the water and resting, indicated by the second, lower part of the horizontal line and the number 2 in the image.

The middle section is the second person wearing the heart rate monitor. The third section of the horizontal line, represented by the number 3, shows the heart rate when not swimming for the second person. From the point where the line begins steering steeply upward, maximum exercise is being performed. The rise and fall of the heart rate is shown in the area represented by the number 4. The horizontal line represented by the number 5 shows the period of resting after exertion.

The last person wearing the heart rate monitor shows an immediate and rapid rise in heart rate shown in the area indicated by the number 6. Following the rapid rise in heart rate, sharp peaks and valleys can be shown in the area indicated by the number 7. Right after swimming stopped, the heart rate monitor was turned off and therefore, no data on the recovering period was found.

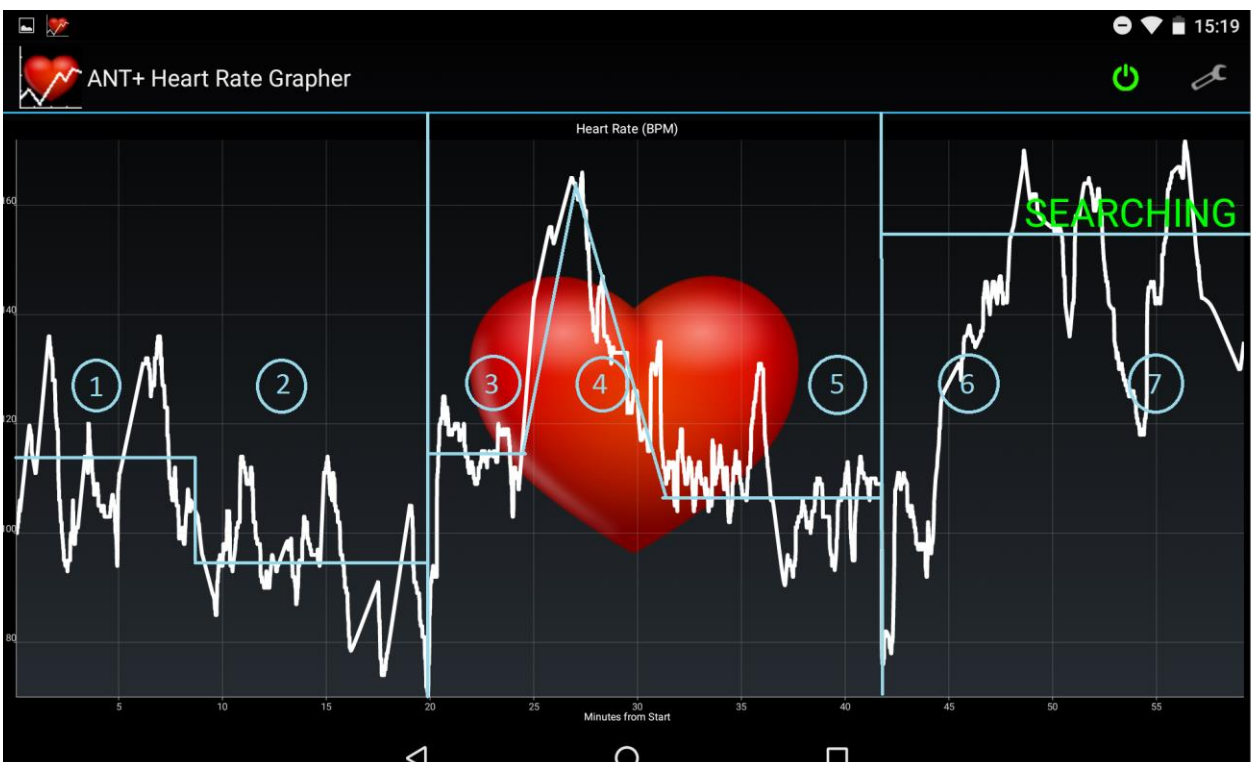

Figure 9 - ANT+ heart rate graph. See text above figure for description.

BLE

The three BLE screenshots are slightly harder to read, and less obvious in their meaning as the program is still in prototype phase. The blue lines represent the Borg upper and lower limits, the green lines represent the heart rate upper and lower limits. The yellow line represents the Borg value as indicated by the person swimming, or in this case, values filled in by the person monitoring the application on the tablet in order to check for heart rate limit responses resulting from certain Borg values. The number 1 indicates the last measured heart rate, the number 2 indicates the date and time of the measurement and the number 3 indicates the last entered Borg value.

Screenshot A represents the heart rate when not swimming, raising to swimming slowly towards the right side of the image. Also, the screenshot shows the lower heart rate limit lowering as a result of the indicated Borg value.

Screenshot B shows the sharp increase in heart rate as the second person wearing the heart rate monitor starts to swim at maximum capacity. This image corresponds to the middle part of the ANT+ screenshot.

Screenshot C shows the last person swimming at maximum capacity, the upper heart rate limit becomes higher as a result of the entered Borg values. This screenshot corresponds to the right section of the ANT+ screenshot.

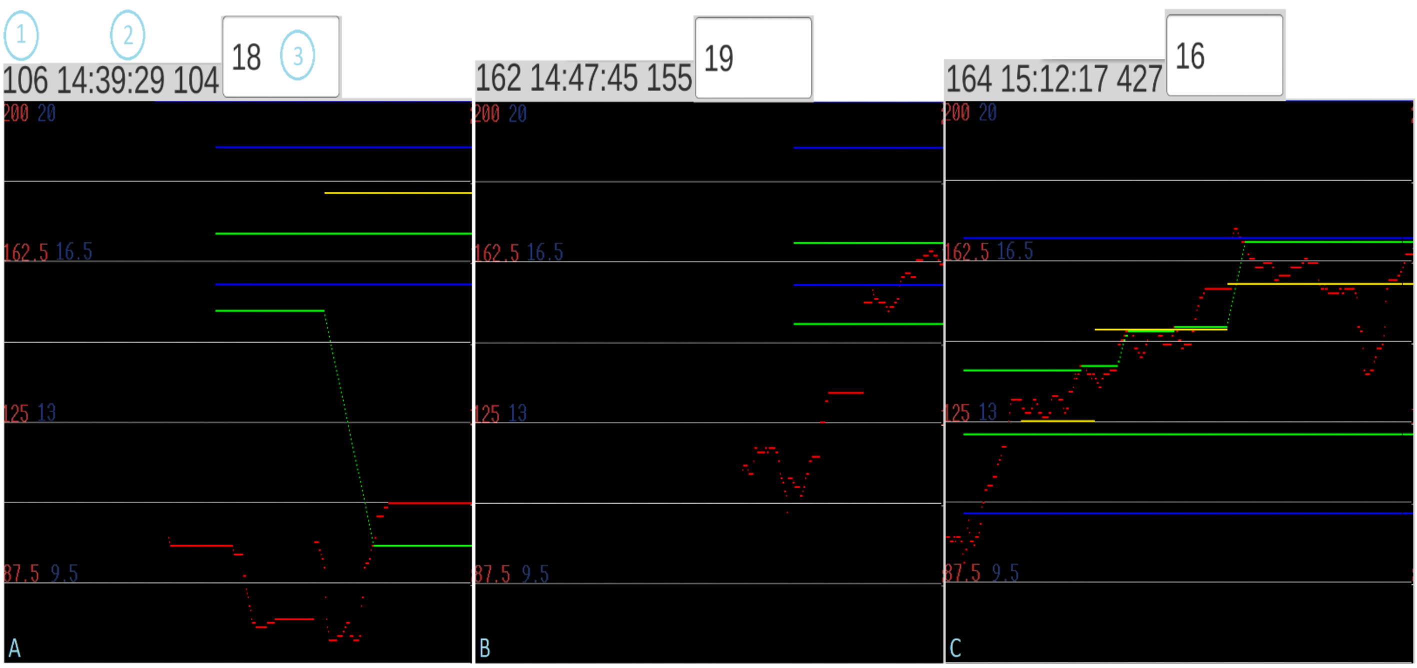

Figure 10 - BLE heart rate graphs. See text above figure for description.

3.4 Experiment discussion

For both ANT+ and BLE protocols, clear distinctions could be made in heart rate differences between stationary, slow swimming and maximum capacity swimming. This is promising, as the heart rate analysis system relies on the possibility to make these distinctions. The heart rate also remained fairly stable with low standard deviation when exercise intensity was kept at a stable level, this is important in managing the heart rate zones. The self-made BLE graph shows this even clearer than the ANT+ stock application graph. Of course the heart rate variability will always differ from person to person, but if it varies wildly due to improper analysis, programming or low sampling rates, the heart rate could fall outside of the heart rate zone unnecessarily too often. From the A and C BLE images, it can be seen that the adaptations to the heart rate limits work as intended. On image A, the Borg value is in the right range when the heart rate is below the intended range, subsequently, the heart rate range is adapted to include the current heart rate. On image C, the opposite case is true, where the current heart rate falls above the intended heart rate zone, but the Borg value falls in the intended range, causing the upper heart rate limit to be adapted to include the current heart rate in the heart rate zone. As the Borg values were set in accordance with the player's indications of physical strain, the system has shown to work as intended. On the whole, the heart rate analysis works as intended during the first prototype tests.

4 Legislation

As the product being developed is for intended use on the European and potentially other markets, certain consumer legislation applies.

Any product sold on the European market, or the European Economic Area (EEA) must have a CE marking. This CE marking signifies the safety, health and environmental protection requirements within the EEA are met by this product. In this manner, businesses know that having this CE mark allows their product to be traded without restrictions within the EEA and customers are guaranteed a level of health, safety and environmental protection [18]. The Food and Drug Administration, or FDA approval in the United States of America is the equivalent of the CE marking in Europe. Similarly, products which are sold in the United States of America need to abide by the regulations set by the FDA [19].

As the program that is being developed is making use of potential medical data, being heart rate and other activity parameters, it is especially important to do some research into the possible legislation requirements the product will be subject to. Specifically, a heart rate monitor which already has a CE marking is used in order to gather heart rate measurements and step counts. This information is subsequently used in calculations and comparisons. User feedback is then delivered in an attempt to motivate the user of the program to increase or decrease the intensity of their exercise by raising or lowering their heart rate.

Through an interview with a legislation expert, information including several legislation documents was obtained. An immediate note was the importance of not only the inner workings of the program or device, but also the claims that are made towards the results of this program or device. Mainly, if any claims are made toward the potential of the program or device to diagnose or treat medical conditions, classification as a medical device will be in effect. Specifically, if information input, medical or not, results in the program providing conclusions about the health or pathologies of a person as output, the program will be classified as a medical device. However, claiming the program could be of aid in attempts to improve one's physical

health does not result in the program being classified as a medical device. Also, a program that takes medical information as input, but does not make any claims regarding diagnosis or treatment of a medical issue, the program will not be classified as a medical device [20].
In the official Medical Device Directive (MDD), a medical device is defined as:

"any instrument, apparatus, appliance, software, material or other article, whether used alone or in combination, including the software intended by its manufacturer to be used specifically for diagnostic and/or therapeutic purposes and necessary for its proper application, intended by the manufacturer to be used for human beings for the purpose of:

- Diagnosis, prevention, monitoring, treatment or alleviation of disease,
- Diagnosis, monitoring, treatment, alleviation of or compensation for an injury or handicap,
- Investigation, replacement or modification of the anatomy or of a physiological process,
- Control of conception,

And which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means;" [21]

As the program is not intended for any of these purposes, but instead for the purpose of motivating a person to ascertain a certain level of exercise intensity, the program falls outside of this definition of a medical device.

Also, according to the same article of the MDD, being article 1, the program does not comply with the definition of an accessory to a medical device. This is because the heart rate monitor used to provide the information for the program is itself not a medical device, therefore the program is not an accessory to a medical device.

The program also does not comply with any of the further definitions given in the MDD, and is therefore not classified as a medical device. [21]

A decision algorithm provided a guidance document on the qualification and classification of stand-alone software shows the classification of the program and is added as Appendix 3.

Through a guidance document provided by the FDA on the policy for low risk devices, the program which is being developed would be classified as a "general wellness product". The purpose of the program is to maintain or encourage a general state of health or a healthy activity. The document also provides a decision algorithm in order to determine whether a device or program is a general wellness product. Going through this algorithm resulted in the affirmation of the program in development being classified as a general wellness product. These products are exempt from examination to determine whether they are medical devices, and therefore do have to abide by the requirements set for medical devices. [19]

In conclusion, through the use of both relevant US and EU regulation documents, no indication was found to assume the developed program would comply with medical device definitions and is therefore exempt from being regulated as such.

5 Future adaptations and recommendations

Of course, the project does not end with the development of a basic heart rate analysis module. Several invalidated additions such as the step counter and the heart rate stability analysis have already been added to the first set of appendices.

The simple step counter analysis can be added using the script in Appendix 1.2. Using this addition, a potential game would no longer be limited to use during only specific activities, but could also provide meaningful analysis of ambient activity patterns of a player. The other addition that has been created, but not yet validated is the heart rate stability analysis. This addition can be used in order to analyze recovery rates after exercise as well as be able to stability of the heart rate during exercise. More of these additions could be thought of and implemented to better cover different aspects of exercise or ambient activity patterns.

Besides the additions to that which already has been developed, there are also some things to look out for. The central heart rate analysis module relies heavily upon the proper input of the experienced intensity levels through the Borg values. Therefore, it is imperative that whatever adaptations are made to make the input of the Borg values a more fluid process, the actual input of the values does not lose its reliability or representativeness through this translation.

Also, a main focus of the game mechanics should be the rewarding of a player to remain in the desired intensity zone. This will allow for proper targeted training instead of merely working towards increasing a players potential to reach and increase their maximum exercise potential.

The central heart rate analysis module as described in section 2.6 of this report works with two relatively simple intermittent inputs: heart rate, which has proven to work during the experiment, and the Borg values, which also work as intended. This allows the module to be used in any game which is intended for use as a motivational or analytical tool during exercise.

As a final remark, it is important to note that the module in its current form is still a very bare bones tool. Many improvements can be made upon its current form, as was the purpose when starting out this project. In its simple form, it works as intended, during further prototyping and game development ideas for expansion and refinement of the module will surely arise. The simple nature of the module makes it very easy to be built upon.

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Appendix 1.1 Script descriptions (heart rate analysis)

```
age                 = 26;
HRrest              = 65;
AD                  = 0;
Intensity           = 2;
HRmax_limit         = 180;

rate_store          = zeros (1,10000);
storesize_limit     =          10000 ;
arraygrowth         = zeros (1,10000);

smallHRadapt        = 5;
largeHRadapt        = 10;
HRbuffer            = 5;
```

In the blue box, the variables are age, HRrest, which is the heart rate of a person when he or she is in rest. The value AD indicates whether the exercises take place in water or not, being 0 for land based and 8 for water based.

Next, the desired intensity level is given, being 2 here. This intensity level can be either 1, 2 or 3, with 1 selected for the lowest intensity exercise and 3 for the highest intensity exercise.

The unboxed line is the maximum heart rate a person may have due to safety considerations.

The green box shows some variables purely intended for the function of the script, these will not be discussed.

The orange box shows the variables for small and large heart rate limit adaptions which are used to alter the limits of the heart rate zones which will be discussed later. The last line provides a variable which allows for a more gradual feedback delivery and will also be discussed later.

```
if Intensity == 1;
    theoretical_HRupper_limit = round(((206.9 - (0.67* age)) - HRrest - AD)*0.6 + HRrest);
    theoretical_HRlower_limit = round(((206.9 - (0.67* age)) - HRrest - AD)*0.45 + HRrest);
    borgupper_limit = 12;
    borglower_limit = 8;
elseif Intensity == 2;
    theoretical_HRupper_limit = round(((206.9 - (0.67* age)) - HRrest - AD)*0.75 + HRrest);
    theoretical_HRlower_limit = round(((206.9 - (0.67* age)) - HRrest - AD)*0.6 + HRrest);
    borgupper_limit = 17;
    borglower_limit = 11;
elseif Intensity == 3;
    theoretical_HRupper_limit = round(((206.9 - (0.67* age)) - HRrest - AD)*0.85 + HRrest);
    theoretical_HRlower_limit = round(((206.9 - (0.67* age)) - HRrest - AD)*0.70 + HRrest);
    borgupper_limit = 19;
    borglower_limit = 16;
end
```

In this next part of the script, the theoretical limits of the zone a person's heart rate should reside in are determined using the Karvonen maximum heart rate formula. Choosing an intensity level in the first part of the script leads to the determination of a heart rate zone and a Borg scale zone.

For intensity 2, the dark blue box is activated, leading to the blue underlined upper and lower hear rate limit determinations through the Karvonen formula. Borg scale limits will also be determined as shown in the orange box, this will allow the script to adapt the heart rate limits to what intensity the person indicates he or she is experiencing, please refer to the section about the Borg scale for further information on how the Borg scale works. The exact mechanics of how the Borg scale is used and how the heart rate zone limits will be adapted as a result of incoming Borg values will be discussed in the next section.

```
HRupper_limit = theoretical_HRupper_limit;
HRlower_limit = theoretical_HRlower_limit;

while counter < 101;
    rate      = 80 + round(rand(1,3)*120);
    meanrate  = round((rate(1,1)+rate(1,2)+rate(1,3))/3);
    borgvalue = round(rand()*19+1);
```

Before the main loop which simulates the exercise data coming in is started, the heart rate limits are renamed in the green box to allow for their adaptations while still holding on to their original values.

The unboxed line containing the blue while statement indicates the start of the main loop.

In the orange box at the start of each iteration, three random values between 80 and 200 will be created to simulate incoming heart rates. These heart rates are stored in the array called rate. The mean of these three heart rate values is taken and stores them in the variable called meanrate to avoid too much peaking up and down of the heart rate, as we are working with random variables. The third line creates a random Borg value to be used in the next part of the script.

```
if meanrate > HRmax_limit
    disp ('You are now above your maximum heart rate limit, slow down!')

elseif meanrate > HRupper_limit
    if      borgvalue > borgupper_limit
        disp ('upper heart rate limit fine, practise too intense')
    elseif (borgvalue > borglower_limit) && (borgvalue < borgupper_limit)
        disp (['borg ok, upper heart rate limit too low, raised by ' num2str(smallHRadapt) ' beats'])
        HRupper_limit = HRupper_limit + smallHRadapt;
    elseif  borgvalue < borglower_limit
        disp (['borg too low, upper heart rate limit much too low, raised by ' num2str(largeHRadapt) ' beats'])
        HRupper_limit = HRupper_limit +largeHRadapt;
    end

elseif (meanrate > (HRupper_limit - HRbuffer)) && (meanrate < HRupper_limit)
    disp ('Nearly going over the upper limit!')
```

After the random values have been created, the meanrate variable is compared to the various limits we have determined in the parts of the script before the main loop is initiated. The comparison with each of these limits will result in a message that will be displayed, seen in the script as the purple lines.

The current mean heart rate is first checked if it is not above a dangerously high heart rate, seen in the red box.

In the dark blue box, the current mean heart rate is checked whether it is above the upper limit of the heart rate zone determined earlier.

If this holds true, it then checks if this corresponds with the simulated Borg value in the light green box. The purple messages show what the three possible outcome comparisons are and what will happen as a result of these outcomes.

For example, the elseif statement before the end statement in the green box shows the case when the heart rate is above the upper heart rate limit, but the Borg value indicated that the person is experiencing an exercise that is too low in perceived intensity for their current desired intensity. This is a large disparity, and as it is decided that the Borg values are used as a reference for the heart rate limits, the heart rate limit will be adapted to increase the likelihood of the current heart rate falling in the heart rate zone. Meaning that for this particular case, the upper heart rate limit will be raised by a fairly large amount, ten beats per minute as determined by the variable largeHRadapt set at the start of the script.

```
elseif (meanrate > (HRlower_limit + HRbuffer)) && (meanrate < (HRupper_limit - 5))
    if      borgvalue > borgupper_limit
        disp (['upper heart rate limit too high, lowered by ' num2str(smallHRadapt) ' beats'])
        HRupper_limit = HRupper_limit - smallHRadapt;
    elseif (borgvalue > borglower_limit) && (borgvalue < borgupper_limit)
        disp ('Doing fine, limits seem ok')
    elseif  borgvalue < borglower_limit
        disp (['lower heart rate limit too low, raised by ' num2str(smallHRadapt) ' beats'])
        HRlower_limit = HRlower_limit + smallHRadapt;
    end

elseif (meanrate < (HRlower_limit + HRbuffer)) && (meanrate > HRlower_limit)
    disp ('Nearly going under the lower limit!')

elseif meanrate < HRlower_limit
    if      borgvalue > borgupper_limit
        disp (['lower heart rate limit much too high, lowered by ' num2str(smallHRadapt) ' beats'])
        HRlower_limit = HRlower_limit - largeHRadapt;
    elseif (borgvalue > borglower_limit) && (borgvalue < borgupper_limit)
        disp (['lower heart rate limit too high, lowered by ' num2str(smallHRadapt) ' beats'])
        HRlower_limit = HRlower_limit - smallHRadapt;
    elseif  borgvalue < borglower_limit
        disp('lower heart rate limit fine, practise not intense enough')
    end

elseif (meanrate > (HRlower_limit - HRbuffer)) && (meanrate < HRlower_limit)
    disp ('keep going!! you are nearly there!')
end

    counter = counter + 1;
end
```

Finally, the lines in the light blue box check whether the current mean heart rate is getting close to the upper heart rate limit for the desired zone. If this is the case, it will display the purple message in the last line. The variable HRbuffer is set to determine the distance from upper limit from which this message will start to be displayed, currently set to be five beats per minute at the start of the script.

The last part of the script is a continuation of the first part of the main loop described in the previous part. The first line of this part directly follows the last line of the previous part and as such is also included in the main loop.

The grey underlined statement in the orange box checks for the heart rate being in the right zone by checking if the current mean heart rate is both higher than the heart rate zone's lower limit and lower than the heart rate zone's higher limit measured from the start of the buffer zones. If this statement is initiated by this case being true, the subsequent lines in the orange box compare the current Borg value with the determined Borg value limits, allowing for heart rate zone adaptations in the same manner as described in the previous part. Again, the purple messages describe what is happening for each case.

In the orange box, the threat of crossing the lower heart rate limit is checked.

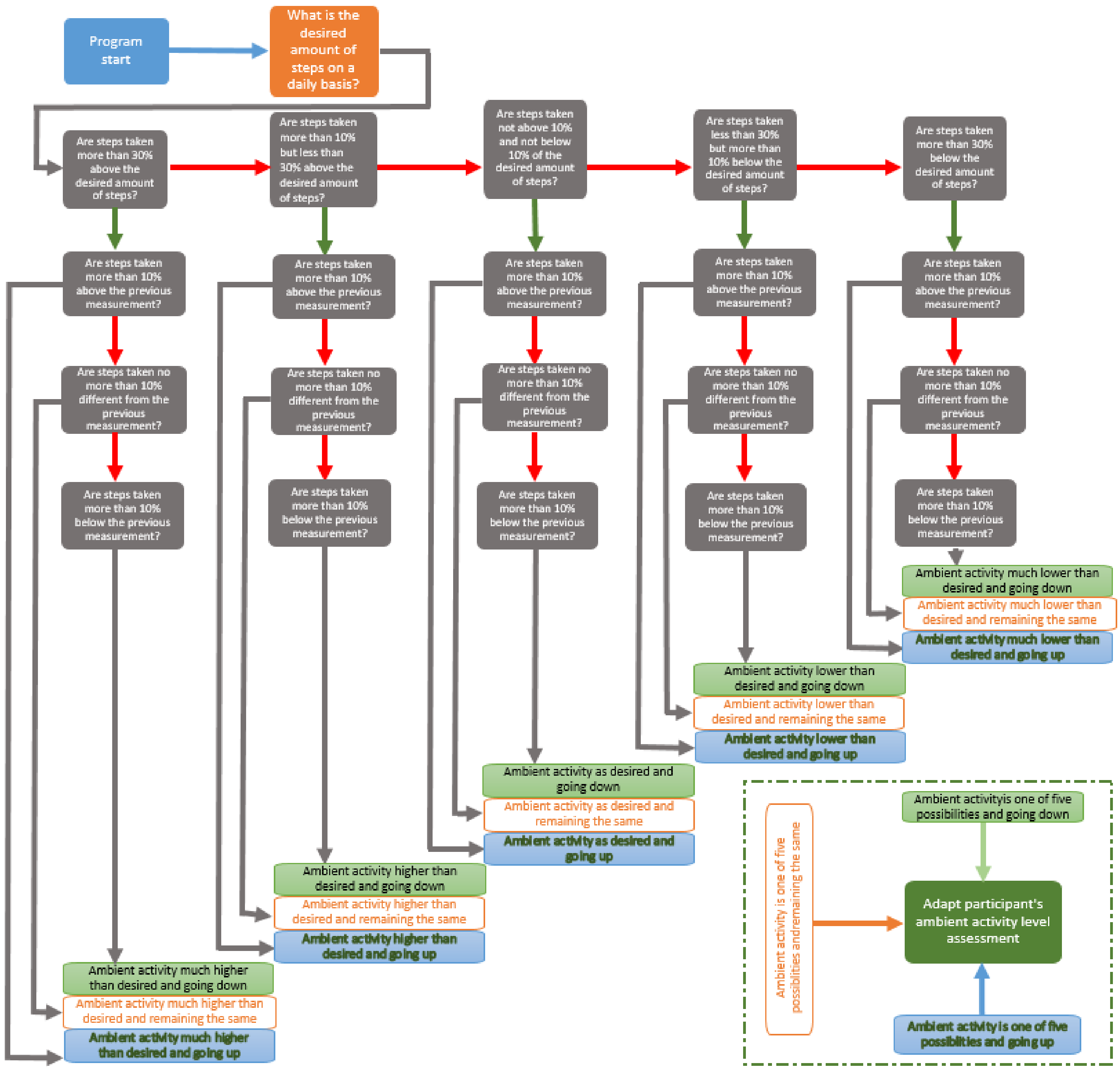
The green box lines check whether the current mean heart rate is below the zone's lower heart rate limit. If this is the case, again the Borg value comparisons are made as in prior cases.

In the dark blue box the current mean heart rate is checked whether it is nearing the lower heart rate limit if it was previously below the zone.

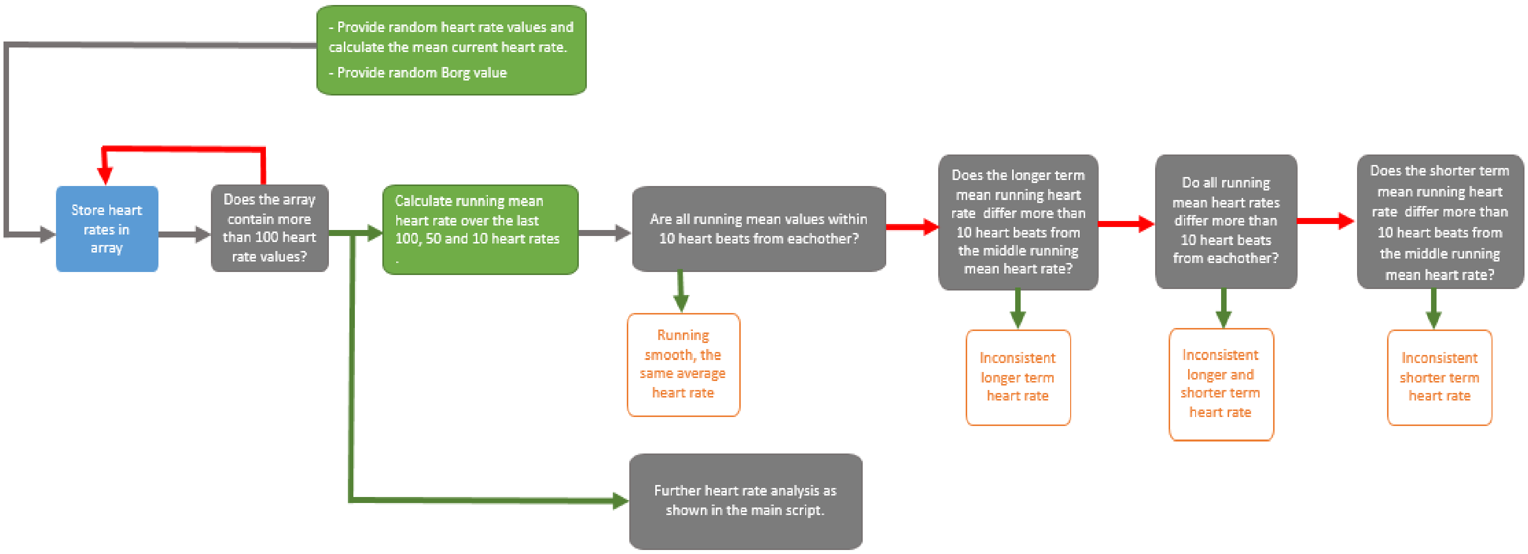
```
disp (['adapted upper limit = ' num2str(HRupper_limit) ' and adapted lower limit = ' num2str(HRlower_limit)])
```

At the end of the script the adapted heart rate limits are displayed by the last line of the script shown above.

Appendix 1.2 Step tracking flow chart



Appendix 1.3 Heart rate stability flow chart



Appendix 2.1 Borg RPE-schaal voor patiënten met coronairlijden en chronisch hartfalen

De Borgschaal is een subjectieve maat voor de belasting van de patiënt of diens reactie op activiteiten.[1,2] Met de Borgschaal kunnen de patiënten leren hun belasting bij hun dagelijkse activiteiten af te stemmen op hun (verminderde) belastbaarheid.[2,3] Ze leren zich tot een bepaalde belastingsgraad in te spannen tijdens hun dagelijkse activiteiten, bijvoorbeeld tijdens sport- en spelactiviteiten.[4]

Op een schaal van 6 tot 20 geven patiënten aan welke mate van vermoeidheid en eventueel dyspnoe en/of pijn op de borst zij ervaren tijdens een bepaalde belasting.

De pols- /hartfrequentiemeting (in rust, maximaal en bij herstel) in combinatie met de Borgschaal is bruikbaar om de patiënt feedback te geven over de normale c.q. abnormale inspanningsverschijnselen. Verder kan de Borgschaal gebruikt worden bij het leren luisteren naar het eigen lichaam, het monitoren/doseren van de belastingsintensiteit, het evalueren van trainingseffecten, het overwinnen van angst voor inspanning, het leren kennen van fysieke grenzen, het vergroten van zelfredzaamheid en tot slot als feedback naar de fysiotherapeut.

Inspanningsschaal op basis van subjectieve waarneming

Schaal	15 punten schaal A	15 punten schaal B
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	heel, heel licht heel licht tamelijk licht iets zwaar zwaar erg zwaar heel, heel zwaar	geen gevoel van inspanning heel erg licht heel licht licht iets zwaar zwaar erg zwaar extreem zwaar maximale inspanning

Bron: Borg[2,3] en Pollock en Wilmore.[5] Deze tabel is overgenomen met toestemming van de oorspronkelijke auteur/uitgever.

Literatuur

[1]]Chen MJ, Fan X, Moe ST. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. J Sports Sci. 2002 Nov;20(11):873-99.

[2] Borg G. Borg's Perceived Exertion and Pain Scales. Champaign (IL): Human Kinetics; 1998.

[3] Borg GAV. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377-91.

[4] ongert MWA, Bebedictus J, Dijkgraaf J, Oldhof J. Het gebruik van de Borgschaal bij bewegingsactiviteiten voor hartpatienten. Maarsen: Elsevier Gezondheidszorg; 2004.

[5] Pollock ML, Wilmore JH. Exercise in Health and Disease: Evaluation and prescription for Prevention and Rehabilitation. 2nd ed. 2009. Philadelphia: W.B. Saunders.

Appendix 2.2 Zes Minuten Wandeltest (6MW)

DOEL(GROEP):	Diagnostisch, prognostisch, evaluatief/effectiviteit, inventariserend De Zes minuten wandeltest wordt gebruikt om het uithoudingsvermogen van patiënten te beoordelen. De test wordt gebruikt bij patiënten met respiratoire aandoeningen, knie- heuparthritis, hartpatiënten, chronische pijnpatiënten, M. Parkinson, COPD en andere chronische aandoeningen.
OPBOUW:	Fysieke performance test bestaande uit één onderdeel. De patiënt wandelt gedurende 6 minuten zo snel mogelijk lopen. De therapeut meet de afgelegde loopafstand.
AFNAMEDUUR:	Ca. 10 min (uitleg: 2 min, de test: 6 min, afronding: 2 min)
BENODIGDHEDEN:	Invulformulier, meetlint, stopwatch, pionnen en evt. loophulpmiddel/orthese Optioneel: een hartslagmeter en pulsoximeter om de fysiologische respons tijdens de test vast te leggen.
RANDVOORWAARDEN:	De test wordt op effen terrein afgenomen, bijvoorbeeld op een gang waar de patiënt voldoende ruimte (minimaal 20 meter) heeft om te lopen en te draaien en waar de gelopen afstand makkelijk kan gemeten worden. Als geen ruimte ter beschikking staat kan test evt. ook buiten uitgevoerd worden.
UITVOERING/INSTRUCTIE:	Vooraf: Bij deze test moet je proberen een zo groot mogelijke afstand af te leggen in zes minuten. Je moet daarbij heen en weer lopen in deze gang. Zes minuten is een lange tijd om te lopen, dat vraagt dus een inspanning. Misschien raak je buiten adem of raak je uitgeput. Je mag langzamer gaan lopen of stoppen en rusten indien dit nodig is. Je mag ook even tegen de muur leunen, maar je moet weer gaan lopen zo snel als dit weer mogelijk is. Nogmaals, de bedoeling van deze test is om zo ver mogelijk te lopen in zes minuten, maar niet gaan joggen of rennen. Consequente stimulatie: Na 1 minuut: “U gaat goed. Nog vijf minuten te gaan.” Na 2 min.: “Blijf zo door gaan. Nog 4 minuten te gaan.” Na 3 min.: ”U gaat goed. U bent al halverwege de test.” Na 4 min.: “Blijf zo doorgaan. Nog maar twee minuten te gaan. Na 5 min.: “U gaat goed. Nog één minuut te gaan.” Na 5.45 min.: ”Over enkele seconden zeg ik dat u mag stoppen. Wanneer ik dat roep, stopt u waar u op dat moment bent en ik kom naar u toe.”
	Na 6 min.: “Roep `Stop' (loop naar de patiënt toe en markeer het punt waar hij/zij is gestopt en meet dit op).” Insluitingscriterium: De cliënt scoort 3, 4, of 5 op de FAC (en loopt dus zelfstandig, niet in loopbrug en niet op loopband).

SCORING:	De afgelegde afstand in meters wordt gemeten.
INTERPRETATIE:	Er zijn normwaarden voor de 6-minutenwandeltest voor gezonde volwassenen tussen 40 en 85 jaar. Met behulp van deze normwaarden kan de uitslag van de 6-minutenwandeltest worden geïnterpreteerd door het resultaat van de cliënt uit te drukken als percentage van het voorspelde aan de hand van leeftijd, geslacht, lengte en gewicht. Een score onder de 82% van wat werd voorspeld wordt gezien als afwijkend. De formule om de normwaarden te berekenen is: **Afstand = 218 + (5,14 × lengte [cm] – 5,32 × leeftijd) – (1,80 × gewicht) + 51,31 × geslacht [1 = man, 0 = vrouw]**

Literatuur:

[1] Butland R. J. A. et al., *Two-, Six-, and 12- minute walking tests in respiratory diseases.* British Medical Journal 1982, 284: 1607-1608

[2] ATS. ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med 2002;166(1):111-7.

[2] Troosters T, Gosselink R, Decramer M. Six minute walking distance in healthy elderly subjects. Eur Respir J 1999;14(2):270-4.

[2] Enright PL, Sherrill DL. Reference equations for the six-minute walk in healthy adults. Am J Respir Crit Care Med 1998;158(5 Pt1):1384-7

[4] Wasserman K, Hansen JE, Sue DY, Whipp BJ, Casaburi R. Principles of exercise testing and interpretation. 2nd ed. Philadelphia: Lea & Febiger; 1999.

Score-formulier Zes Minuten Wandeltest

Datum				
Afstand*				
Tijd, indien patiënt eerder stopt				

*Afstand in meters

Opmerkingen 6MW: bv test niet afneembaar, reden:

____

Appendix 2.3 Uitvoeringsstandaard Astrand fietstest

Achtergrondinformatie:
De Ästrand fietstest[1-3] is een test om het fysieke uithoudingsvermogen te meten. Het is een submaximaal test. D.m.v. de berekening van de VO2max of het aflezen van een nomogram[1, 4] kan een indruk van het uithoudingsvermogen worden verkregen.

Benodigdheden:
Fietsergometer, hartslagmeter, Astrand & Rhyming nomogram met leeftijdscorrectie.

Uitgangshouding:
De patiënt doet een hartslagband om en neemt plaats op de fiets. Stel het zadel op de juiste hoogte in, zodanig dat in de laagste stand van het pedaal, de knie zeer licht is gebogen (170º).

Instructie:
U gaat fietsen met een snelheid van ongeveer 60 omwentelingen per min. U krijgt eerst een korte warming-up van 2 min. Hierna wordt (eventueel in korte stappen) de beoogde testbelasting ingesteld. De test duurt ongeveer 6 min. met daarna een cooling down.

Uitvoering:
Warming up: laat de patiënt eerst ±2 min. met een laag wattage fietsen. Breng vervolgens het wattage op de testbelasting (eventueel in korte stappen). Trapfrequentie wordt tussen 50-60 omwentelingen per min gehouden. Ieder minuut wordt de hartfrequentie (HF) gemeten. De laatste twee minuten wordt de HF iedere 15 sec. gemeten. Indien een min of meer constante HF (steady state, niet meer dan 5 sl/min verschil) wordt bereikt wordt de gemiddelde HF van de laatste twee minuten berekend. Na de 6de min. vindt een cooling down plaats waarna de test is afgelopen. De VO2max wordt berekend met behulp van het Astrand & Rhyming nomogram (Figuur 1) met leeftijdscorrectie (Tabel 1). Vanaf de verticale lijn met de gefietste belasting trekt men een lijn naar de gemiddelde HF. Men leest het maximale zuurstof verbruik af en vermenigvuldigt dit indien nodig met de leeftijdsfactor.

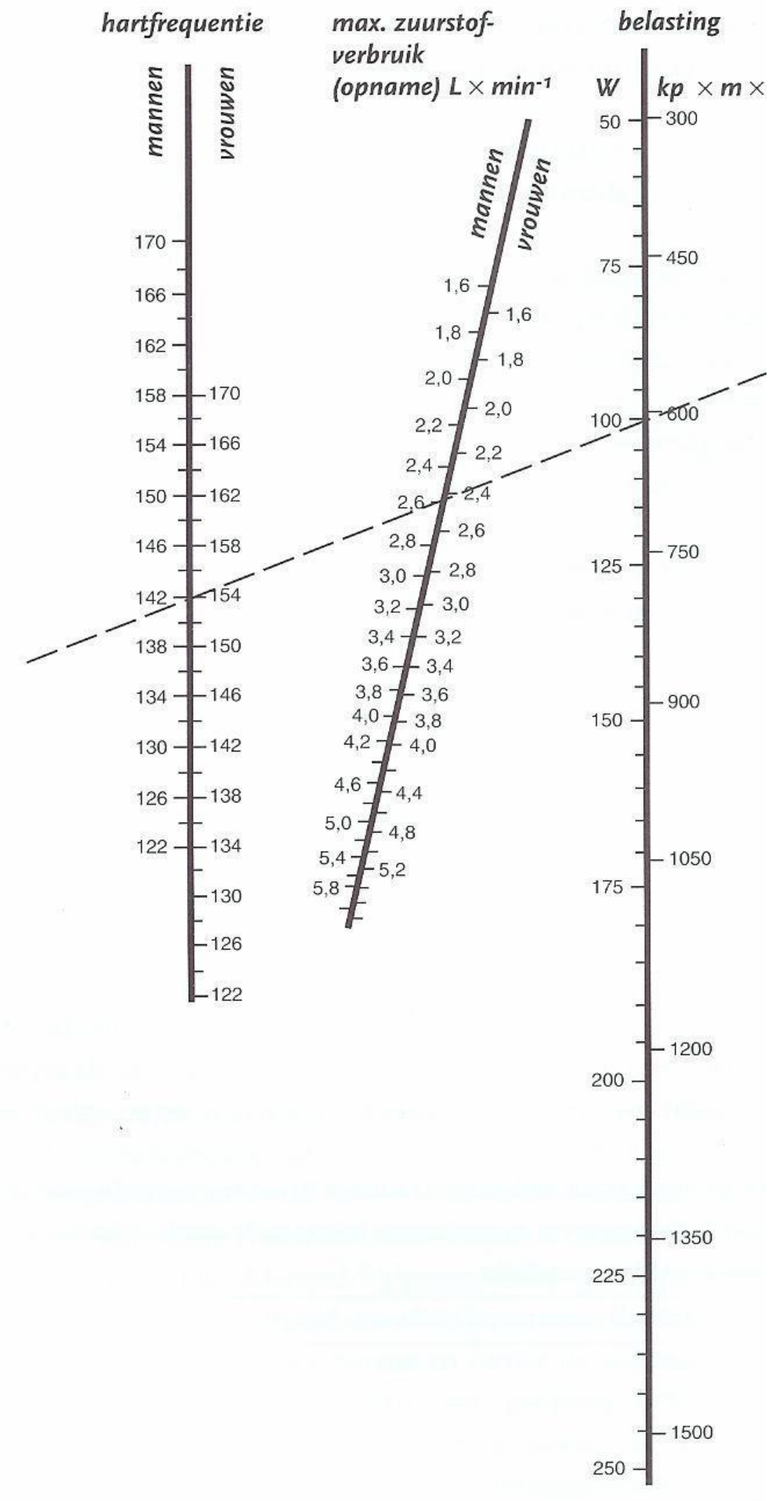
De HF moet boven de 130 slagen/min komen om een valide berekening te kunnen doen[1].

Indien dit niet het geval is dient het wattage te worden opgevoerd tot de HF boven 130 slagen/min komt en wordt er weer gefietst tot de steady state is bereikt, welke 2 min wordt volgehouden.

Indien de HF de maximaal benadert (gelet op de leeftijd van de patiënt) wordt de test afgebroken.

Gebruik eventueel een RPE schaal om de ervaren inspanning te meten.

Figuur 1. Astrand & Rhyming nomogram



Tabel 1. Astrand & Ryhming Fiets Ergometer Test: Correctie factor voor leeftijd of bekende maximale hartfrequentie[a](HF)

Leeftijd	Factor	Maximale HF	Factor
15	1.1	210	1.12
25	1	200	1
35	0.87	190	0.93
40	0.83	180	0.83
45	0.78	170	0.75
50	0.75	160	0.69
55	0.71	150	0.64
60	0.68		
65	0.65		

a Gebruik de correctie factor wanneer de patiënt boven de 30-35 jaar is of wanneer de maximale HF bekend is. De waarde uit het nomogram moet worden vermenigvuldigd met de correctie factor[4]

Referenties

[1] Astrand PO, Ryhming I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. J Appl Physiol 1954; 7(2):218-221.
[2] Astrand PO. Human physical fitness with special reference to sex and age. Physiol Rev 1956; 36(3):307-335.
[3] Astrand PO. Quantification of exercise capability and evaluation of physical capacity in man. Prog Cardiovasc Dis 1976; 19(1):51-67.
[4] Cink RE, Thomas TR. Validity of the Astrand-Ryhming nomogram for predicting maximal oxygen intake. Br J Sports Med 1981; 15(3):182-185.

Appendix 3 Decision diagram to assist qualification of software as a medical device [22]