Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Computer Science

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Creating Exercise Programs For Patients With Metabolic Syndrome Through Artificial Intelligence With The Genetic Algorithm

Master's thesis in Master of Science in Informatics
Supervisor: Pauline Catriona Haddow
June 2022

NTNU
Kunnskap for en bedre verden

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Abstract

Overweight and obesity is a rising problem in the world. Sedentary lifestyles with decreasing amounts of exercise and easier access to processed foods has led more than two billion adults to being overweight, with roughly 650 million of these being obese. Worldwide obesity has tripled since 1975. As a result, the cases of cardiovascular diseases and cases of type 2 diabetes has skyrocketed. A common term used to describe the risk factors of such diseases and conditions is Metabolic Syndrome, which is a cluster of clinical risk factors such as hypertension, and hyperglycemia. Reverting Metabolic Syndrome is vital in order to improve the health status of such patients. With the most important factors being diet and exercise.

Current methods of exercise shows good results in reversing metabolic syndrome, but often the patients fall back to old habits after a period of time. The motivation and discipline needed to improve ones health can not be underestimated. To promote consistency for the patient, the training regimen should therefore be tailored according to the health and debilitation of the individual. This could potentially improve their chances of reversing metabolic syndrome for the rest of their lives

Known for its ability to solve difficult tasks, artificial intelligence has in recent years become a common way to solve varying kinds of optimization problems by finding solutions where humans struggle to. This work dives in to how artificial intelligence and the Genetic Algorithm can be utilized to solve the optimization problem of creating exercise programs for patients with metabolic syndrome.

Sammendrag

Overvekt og fedme er et økende problem i verden. En stillesittende livsstil med avtagende treningsmengder og lettere tilgang til prossessert mat har ført til at mer enn to milliarder voksne har blitt overvektige, og omtrent 650 millioner av disse har fedme. På verdensbasis har fedme tredoblet seg siden 1975. Som et resultat har tilfellene av hjerte- og karsykdommer og diabetes type 2 økt drastisk. Et vanlig begrep som brukes for å beskrive risikofaktorene for slike sykdommer og tilstander er metabolsk syndrom, som er en klynge av kliniske risikofaktorer som hypertensjon og hyperglykemi. Reversering av metabolsk syndrom er avgjørende for å forbedre helsetilstanden hos disse pasientene, hvor kosthold og trening er de viktigste faktorene.

Dagens treningsmetoder viser gode resultater for å reversere metabolsk syndrom, men ofte faller pasientene tilbake til gamle vaner etter en tid. Motivasjonen og disiplinen som trengs for å forbedre egen helse bør ikke undervurderes. For å fremme konsistens for pasienten, bør treningsregimet derfor skreddersys etter den enkeltes helsestatus og muligheter. Dette kan potensielt forbedre sjansene deres for å reversere metabolsk syndrom for resten av livet.

Kjent for sin evne til å løse vanskelige oppgaver har kunstig intelligens de siste årene blitt en vanlig måte å løse ulike typer optimaliseringsproblemer ved å finne løsninger der mennesker sliter. Dette arbeidet undersøker hvorvidt kunstig intelligens og den genetiske algoritmen kan brukes til å løse optimaliseringsproblemet som er å lage treningsprogrammer for pasienter med metabolsk syndrom.

Preface

This thesis constitutes the work of a master's thesis in artificial intelligence written at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, in the period 10.01.2022 - 13.06.2022.

My deepest gratitude goes out to my supervisor Pauline Haddow for her never ending enthusiasm about steering me in the right direction and excellent supervision this last year. In addition to Pauline, my fellow students at the CRAB Lab also provided helpful insight and knowledge in the field of bio-inspired artificial intelligence. I would also like to thank Jannicke Ferger and Håkon Moen for their medical advice and knowledge that have been a big help during this work. Lastly, i would like to thank anyone reading this thesis for their interest in my work.

Erling Moen
Trondheim, June 13, 2022

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Chapter 1

Introduction

This opening chapter serves as an introduction to the thesis and the motivation behind it, followed by the research goal and questions. The introduction also includes a look at the research process and an overview of the thesis structure.

1.1 Background and Motivation

Exercising has been practiced by humans for thousands of years. During this time, Exercise Programs(EPs) have been developed and adjusted to fit the needs and ambitions of the individuals and/or groups of humans performing them. In modern days, creating EPs has become a full time job for personal trainers, physiotherapists and others. Through many years of trial and error, the EPs are getting more efficient, but how and when will EPs approach optimality in terms of time and energy spent and the results on the person exercising?

To understand how to exercise optimally, we must first clearly state what the goals and ambitions of the person executing the program are. Whether the goal is to become faster, stronger or improve health conditions, the program should be specifically tailored to the needs of the individual.

Artificial Intelligence(AI) is rapidly becoming a larger part of the modern world. Self driving cars, weather reports and voice assistants are just a few examples of the limitless application areas of AI. Through algorithms and data sets, AI has become a powerful tool to help humanity going forward. An area where AI is particularly good is optimization problems, and problems where several objectives has to be balanced and optimized.

This thesis investigates how EPs have been made for people with Metabolic Syndrome(MS) and how suitable these programs have been in improving their health conditions. While AI may struggle to accurately model a human and the process of exercising, depending on the level of abstraction, it has the advantage of clever algorithms and modern computing power capable of simulating millions of people doing the exercises. For this reason, giving AI and specifically evolutionary algorithms a chance to create EPs seems like an area worth further investigating.

1.2 Goals and Research Questions

Goal *Solve the multi objective optimization problem of creating EPs for people with MS by utilizing artificial intelligence.*

The overall goal of this thesis is to create more efficient EPs for people with MS. Beginning to exercise can be a big leap for some of these patients, which means an EP that is simple to follow and gives good results from a minimum amount of effort could be life saving. This can be seen as a multi objective problem which could be solved by AI.

Research Question 1: *To what abstraction level must a human be accurately modeled so as to balance accuracy and complexity of the model to produce realistic training programs from a genetic algorithm?*

The abstraction level of the human model used in this work plays an important role in the fitness test of the GA 3.4.2. The more details that are included the more accurate the results, but this question considers whether a simple model can be good enough to produce realistic results.

Research Question 2: *In which ways will the produced EPs from an evolutionary algorithm differ from traditionally made EPs?*

Being that the evolutionary algorithm is based on pseudo-random evolution of generated EPs, the resulting EPs may differ vastly from. This questions digs deeper in to the differences between the EPs created by AI and industry standard EPs for patients with MS.

Research Question 3: *What effect does a simulated exercise period have on the health parameters of a patient with Metabolic Syndrome?*

The effects of ordinary cardiovascular exercise on metabolic health parameters can be found in many research articles 2.3, this research question is designed to find the results an EP created by AI has on these patients in a simulated exercise environment.

1.3 Assumptions and Restrictions

This thesis includes several different fields of science: medicine, exercise physiology and computer science. These fields however, are too large to include all aspects in this work. Some features and aspects that could be included are left out because their inclusion goes beyond the scope of this thesis. The research in this thesis is therefore based on some assumptions.

Assumption 1: Diet
Improving the health parameter of a patient with MS consists of both diet and exercises, this work however, is focused on the exercise part of the equation. That means that it is assumed that the diet of the test patients seen in the fitness test's simulator seen in section 3.4.2, is optimal and non-varying between the patients.

Assumption 2: Health Conditions and Diseases
The thesis does not take into account any diseases or health conditions that a human may have in addition to anything related to MS.

Assumption 3: Other metabolic parameter adjusters
It is assumed that the test people do not get their metabolic parameters adjusted or affected by any other life event other than living normal lives. Even though these parameters naturally differ from day to day based on many factors, those factors are not included as part of this thesis.

Assumption 4: Complexity of Exercise Simulation
This work includes the implementation of fully functional exercise simulator that takes patients as input and creates EPs for them based on their health. This is modelled as realistic as possible given the scope of this work, but it is still only a simulation. That means that the results are not guaranteed to be accurate and some factors that possibly could be included in the simulator to make it closer to real life, are left for future work.

1.4 Research Method

The research method used in this thesis has been an analytical one. The field of planning exercises and writing EPs for people with MS has been explored for their advantages and disadvantages. Further, the current state of the art evolutionary algorithms used in AI has been researched to find candidates for a method to create the EPs.

1.5 Research Process

The research process was started with an initial literature search to find a meaningful and interesting topic to cover in the thesis. Next, a structured literature review was conducted to find the most relevant literature. Finally the structured literature review process was used to review the literature found and to discover potential application areas.

Initial Literature Search

The initial literature search began by looking at recent articles on how bio inspired methods had been applied to solve different problems. As it turned out, evolutionary algorithms as a search heuristic such as the genetic algorithm(GA) seemed to have a wide area of possible applications which made it an interesting starting point to further explore.

After reading articles on GAs, a natural application field seemed to be the search of optimality in a field that struggled to find it. Creating EPs is a field with numerous different factors to weigh, consider and optimize in order to create an EP that fits a person perfectly. Also, such a perfect EP has probably never been created as there are too many objectives to observe and adjust for. An evolution based multi-object optimization algorithm such as the GA seemed like an interesting way to approach this problem to possibly rectify the situation and create closer to optimal EPs than has previously been done by humans.

By more optimized it is meant that the EP can generate better results on the human body and health for the same or less effort that previous EP's have done. Applying GA to creating EPs was further explored. The search continued with finding articles on how AI had been applied in exercise physiology to create closer to optimal EPs for either a subgroup of people or people in general. Reading more into different kind of peoples health struggles, a topic that seemed important was MS; a health problem closely linked to inactivity. As the problem of creating EPs is multi-objective in its nature, and these patients needed EPs, it seemed like an interesting area to apply the GA to find solutions. Other application areas were also considered as can be seen in section 1.5.

Structured literature Review Protocol

In order to find relevant and recent work in the application area of EP creation for patients with metabolic disease and recent methods used in AI, a structured literature review protocol was formed. The questions used to guide the search were: How are EPs currently made for patients with metabolic disease? How has AI been used in the development of EPs?

Search Terms	Metabolic diseases, exercise planning, evolutionary algorithms, genetic algorithms, artificial intelligence, multi-object optimization
Inclusion Criteria	• Literature should focus on metabolic diseases and/or exercise planning for specific groups. • Articles have to appear relevant after reading only the abstract and conclusion. • Literature should be self critical and be transparent about the strength and weaknesses of the its work. • The literature shall be no older than 4 for AI and 15 years for research on exercise
Evaluation Criteria	• Clear analysis and synthesis presented and conclusions strongly supported. • Appriopriate resources examined and covered in depth, significance of research critiqued. • Results from the literature should be reproducable by following the process description and model of the literature

Table 1.1: Search terms and selection criteria

Structured Literature Review

After completing the initial literature search and writing the structured literature review protocol, a structured literature review was conducted to select the most relevant literature for this thesis. This process started by exploring different groups of people that could benefit from an EP tailored specifically for them. Several such groups of people were found and further investigated.

EPs for top level athletes Creating EPs for top level athletes seemed like an interesting area to further explore. Particularly Olympians or other world class athletes in running events. The importance of optimality for their training and also the fact that they have a very high chance of actually following the correctly executing the EP was the main reasons this was considered. The idea of working with talented people seemed intriguing. However, beyond the completion of this work lies a need to do real life tests on a bigger scale to confirm the results of this thesis' conclusions, which seems too hard to actually pursue. Thus, the idea of working with top level athletes was dropped.

EPs for any person Creating a model and evolutionary algorithm that can could take any person as input and create a program for them seemed very interesting, but the scope of the project would be too large for this thesis. This is because the amount of variables needed to accurately differentiate between individual people is considerably larger than making program for a specific group of a people.

Exercise programs for patients with metabolic disease People who suffer from MS often have a very clear way to improve their health condition. That is: diet and exercise. This seemed like an interesting challenge because creating the optimal EP does not only revolve around the optimal exercises, but rather exercises that give good results while not being too demanding. In its essence, the algorithm should produce an EP that the person is willing to do or build upon for the rest of their life. Based on their own goals and motivation. This program should be perfectly balanced between effort and results such that the needed results come at a price that the user is willing and able to pay.

1.6 Thesis structure

The rest of the thesis is structured as follows: Chapter two presents the background information needed to understand the concepts behind this work. Chapter three describes the methods used in this work. The Exercise Simulator the implementation of the GA and how the patients and EPs have been modelled. Chapter four presents the results and evaluation of the results. Chapter five is the final chapter where the results are discussed and a conclusion of the overall research is made, as well as the contributions made and possible future work.

Chapter 2

Background Theory and Motivation

This section presents the necessary background theory needed to understand the concepts in this thesis. The first part covers the medical knowledge about MS needed to understand how and why exercise is vital for patients with MS. The second part covers the technical knowledge needed to understand how the implementation of artificial intelligence and specifically the GA is used in this work.

2.1 Metabolic Syndrome

MS is not a specific disease, but a collective term defined as a cluster of at least three out of five clinical risk factors that commonly occur together: abdominal visceral obesity, hypertension, elevated serum triglycerides, low serum high-density lipoprotein cholesterol (HDL) and higher fasting blood glucose levels due to insulin resistance. [ClevelandClinic, 2019]

The more of these conditions a patient have, the higher the chance of developing serious health issues. Also known by the names: Syndrome X, Insulin Resistance Syndrome and dysmetabolic syndrome; it increases the patients risk of heart disease, stroke and type 2 diabetesPaley and Johnson [2018]. Table 2.1 state the criteria for having each of the risk factors and table 2.2 show the normal ranges for these health parameters. The data of the tables are gathered from the Cleveland Clinic [ClevelandClinic, 2019].

	Waistline	**Fasting Blood Glucose**	**Blood Pressure**	**HDL Cholesterol**	**Triglyceride**
Unit	Inches	mg/dl	mm/Hg	mg/dl	mg/dl
Men	>40	>100	>130/85	<40	>150
Women	>35	>100	>130/85	<50	>150

Table 2.1: Dangerous Metabolic Syndrome Health Parameters

	Waistline	**Fasting Blood Glucose**	**Blood Pressure**	**HDL Cholesterol**	**Triglyceride**
Unit	Inches	mg/dl	mm/Hg	mg/dl	mg/dl
Men	<40	<100	<120/80	>40	<150
Women	<35	<100	<120/80	>50	<150

Table 2.2: Normal Metabolic Syndrome Health Parameters

2.1.1 Common Diseases and Conditions

There are several types of diseases and conditions connected to MS. The most common ones are cardiovascular diseases such as coronary artery disease and stroke. Excess weight on the body can lead to a patient developing insulin resistance, this can in turn cause the patients blood glucose levels to rise, eventually this can lead to type 2 diabetes [Wyller, 2019]. High cholesterol and high blood pressure increases the risk of atherosclerosis. This may cause plaques to build up in the patients arteries. The plaque occurs inside the veins, and is transported with the blood before it eventually gets stuck in a smaller vein and causes a blood clot. The clot can happen in a patients arteries or veins which increases the chances of a blood clot, in a patients brain, causing a stroke, in the heart, causing a heart attack or elsewhere in the body such as a leg causing deep vein thrombosis.

2.1.2 Risk Factors

The reason why these disturbances occur at the same time is somewhat unclear [Wyller, 2019]. But it is known that physical inactivity and high intake of saturated fats through diet are strongly connected to a persons health parameters. MS is therefore associated with an unhealthy lifestyle and being overweight.

There are a number of other risk factors that may increase a persons chance of developing MS. First off, the chance increases with age. Next, obesity. A person is also more likely to have MS when they are genetically predisposed and have family history of type 2 diabetes. Other diseases that may increase the risk are nonalcoholic fatty liver disease, polycystic ovary syndrome or sleep apnea. Finally, a sedentary lifestyle also increases the chances of gaining weight and is therefore a secondary risk factor[MayoClinic, 2021].

2.1.3 Treatment

The treatment for MS is focused on life style changes such as physical activity and weight loss or targeting specific symptoms such as anti hypertensive medications for hypertension [Stubberud, 2016]. The purpose of treatment is to avoid complications such as various cardiovascular diseases and type 2 diabetes. Research shows that physical activity such as walking, jogging or running has a good effect in the prevention ant treatment of MS and the associated complications [AHA, 2021a]

2.1.4 Importance of Motivation

Substantial lifestyle changes and sufficient effects of the treatment requirements motivation[Eide and Eide, 2017]. Motivation is essential when it comes to change as there is a strong correlation between motivation and results. If the patient is repeatedly not experiencing any improvement in their health condition, their motivation to comply with the treatment may decrease [Kristoffersen et al., 2016]. The patients may find it difficult to uphold the changes in their life style. A lack of motivation may be one of the reasons the patients do not comply with the changes in lifestyle. It is vital that the patients find motivation for themselves and firmly decide that they want a change.

2.2 Exercise physiology

Exercising is meant to improve the human body and mind by giving different health benefits. There are numerous reasons why a person might want to exercise, to become stronger, faster, more agile, more mobile or simply just to look better on the beach. Though more importantly it can also be to live a longer, healthier life.

2.2.1 Exercising to Improve Health

Long term weight management is extremely challenging due to interactions between our biology, behaviour and the obesogenic environment. The rise in obesity in the past several decades can largely be explained by the industrialization of the food system. Ultra processed foods now contribute the majority of calories in America which in turn has led to a drastic weight average weight. In addition, lifestyles has become more sedentary with modern jobs and lifestyles. The combination of these two factors has led individuals to increased food intake, decreased activity and ultimately, weight gain[Hall and Kahan, 2019].

To exercise with the goal of improving health status is a very complex problem involving many factors. One might think that simply burning more calories by moving more is key, and that is not wrong. In its essence, losing weight is all about how many calories a person consumes and how many calories a person spends. After all, a person cannot keep its weight if it burns more fuel than it consumes. This means that in order to lose weight, a person can either eat fewer calories, burn more calories, or both.

To exercise with the goal of improving health status is a complex problem involving many factors that have to be considered. When exercise is prescribed as a way to improve a patients health it is generally linked to the patient having one of the risk factors of MS as seen in section 2.1. To combat these risk factors, the main goal of the the exercises is to make to patient lose weight, which will in most cases improve their health status[AHA, 2021b].

The American Heart Association recommends three steps in order to combat MS. First off the patient has to eat a healthier diet, second they have to get more active and third they must lose weight. The recommended dosage of activity is 150 minutes of moderate intensity physical activity per week. Walking is a good start but other activities that gets the patients heart rate up works as well. To lose weight the patient has to burn more calories than they consume. This combines to living a healthy lifestyle with a balance of exercise and diet to rid the patient of the MS risk factors.

Seemingly a very simple concept, but simple does not necessarily mean easy. These measures may be a drastic change in a persons life and may require a great deal of motivation, encouragement and discipline as seen in section 2.1.4. It is absolutely necessary that the person who has been diagnosed with MS is willing to make these changes for themselves in order to succeed in transforming their lifestyle permanently in order to get healthy. An EP that is easy to grasp, with simple workouts and with no more effort than what is absolutely necessary to rid them of the MS definition could be a big help in the right direction.

Research shows that most people who try to change their life by eating healthier and exercising more, ends up going back to their old lifestyle eventually[Hall and Kahan, 2019]. The problem is not just how to find ways to change the persons life, but how it can remain changed. There is little reason to go on a diet and exercise for a few months if the person can not manage to maintain this lifestyle over time. Therefore the measures taken needs to be measures that can be be upheld for the rest of the persons life. This is why it is important to make small changes that can have a big impact. An EP that is optimized to get as much results as possible for as little effort as possible could be a big help here. The EP could be continually developed and adjusted to the persons needs and goals as long as they live.

2.2.2 Creating Exercise Programs for Patients

An EP is made as a plan for what kind of exercise a patient should do for a period of time. The program typically includes which days the exercises should take place and what kind of exercises should be done on those days. For aerobic exercise they will typically include an intensity measured in heart rate or pace that should be held during the exercise and a duration of the exercise. For example it may say that one should run for 20 minutes at 80% of maximum heart rate. For a strength training program it typically says how many repetitions, how many sets and how much weight should be lifted for each exercise. As an example the program could say that one should perform the bench press exercise with 80kg of weight on the bar, for three sets of eight repetitions. The EP for a period of time will include all the necessary information a patient needs to know what exercises to do for that period of time.

Creating these programs is a skill performed by personal trainers, medical doctors, physiotherapists, coaches and several other professions, many people also choose to create their own EPs or have a friend or mentor create it for them. Depending on the goals and expected results of the exercise period, one or several of these people could be the right person to create the program. EPs are made for several reasons, for example it could be to become the best 200m runner in the world, to lift heavy weights, to become muscular or to improve ones health. Regardless of what the goal of the exercise is, the way EPs are typically created are fairly similar for all.

1. Assess fitness and health status
Before starting to exercise, it is important to assess your level of fitness so as to not start off too hard or too easy. One should also check their health status in order to identify areas of improvement.

2. Identify the goals
Before a plan is created, a patient should identify what their goal with performing the workout regimen is. For patients with MS this typically means which health parameters are at risk and figure out how they can be improved through exercise.

3. Create a plan to achieve those goals
After the goals are identified, one must lay a plan on how those goals can be achieved. In most cases, the goal for patients with MS is losing weight as seen in section 2.1, which should be the main focus of the exercises of any patient with MS.

4. Perform the exercises over a period of time
The next step is to actually perform the exercises that have been planned. This typically involves going through a four, eight or more weeks of executing the exercise plan.

5. Assess fitness and health status After the workout period is complete, the patient can again assess their fitness and health status by talking to their doctor. After this, new goals are set and the steps repeat themselves. It is important to note that the diet and exercise changes in a patients life must be upheld as long as they live to stay rid of MS.

2.3 Effects on Metabolic Syndrome by Exercise

This section takes a look at research done on what effect exercise regimens has had on the health parameters of patients with MS. Several kinds of studies are included such as pilot studies, systematic reviews and meta analyses and randomized controlled studies. The main reason why this section is important was to gain information to be able to build health parameter change equations that are used in the model of this thesis, more on that in section 3.5.

2.3.1 Exercise Regimens in General

A 2007 study published in the The American Journal of Cardiology[L.Johnson et al., 2007] researched the effects of exercise training amount and intensity on MS. The objective of the study was to determine how much exercise is recommended to decrease the prevalence of MS. The study started with 334 randomly assigned subjects, 227 finished and 171(80 women, 91 men) had complete data for all 5 Adult Treatment Panel III-defined MS risk factors and was included in the analysis. The subjects were randomly assigned to either a 6 month control or 1 out of 3 eight-month exercise training groups. Group 1 was assigned low amount/moderate intensity, equivalent to walking 19km/week. Group 2 was assigned low amount/vigorous intensity, equivalent to jogging 19/km week. Group 3 was assigned high amount/vigorous intensity, equivalent to jogging 32km/week.

The study found that Group 1 improved MS relative to the inactive control group. Group 2 which did the same amount of exercise, but at a higher intensity improved more, but not significantly suggesting that lower intensity may be more effective in improving MS. Especially because the people doing the exercises have an easier time performing lower intensity workouts, this may also be more viable as a long term exercise plan. The study concluded that a modest amount of moderate intensity exercise in the absence of dietary changes significantly improves MS, which further supported the standard recommendation that adults get 30 minutes of moderate intensity exercise every day. Table 2.3 displays the prescribed exercises and the adherence to the regimen for each of the three groups.

Variable	**Low Amount Moderate Intensity**	**Low Amount Vigorous Intensity**	**High Amount Vigorous Intensity**
		Prescribed Exercice	
Intensity (% peak oxygen consumption)	40% - 55%	65% - 80%	65% - 80%
Prescription amount (km/wk)	19.3	19.3	32.2
Prescription time (min/wk)	205+-43	128+-29	200+-38
		Actual Exercise done	
Adherence	88(14%)	92(10%)	86(11%)
Actual amount (km/wk)	17.0	17.8	27.7
Actual time (min/wk)	179+-37	114+-29	175+-36
Frequency (sessions/wk)	3.5+-0.6	3.0+- 0.5	3.7+-0.7

Table 2.3: Exercise prescription and adherence by group

2.3.2 Randomized Controlled Studies

A 2004 paper[Carroll and Dudfield, 2004] investigated the increased attention to the complex role of multiple metabolic abnormalities in the development of related chronic diseases such as type 2 diabetes mellitus and cardiovascular disease. One of the major goals of the study done was to investigate the effects of exercise on the major components of the MS. It was found that the majority of the Random Controlled Trials(RCT) reviewed for exercise on metabolic abnormalities have prescribed aerobic exercise for 3-5 days a week, typically for a duration of 30-60 minutes and a relatively moderate to high intensity(60% of maximal aerobic capacity). Furthermore, concern was that no matter how substantial the benefits, these exercise regimes may be difficult to sustain in overweight/obese patients.

A 2019 randomized controlled study[Chiang et al., 2019] done on the effects of walking on body composition and MS split thirty two adults with obesity into three groups. One with was assigned a walking step goal of 12000 steps per day(WSG), one had the same goal but also had the requirement that for at least three days of the week, the step pace had to be at least 103 steps per minute(WEG). The last group was a control group which lived a free-living lifestyle with no requirements(CG). The variables of MS and body composition were measured before and after intervention. The participants had a (mean (s.d.) age: 19.72 (0.80) years; height: 165.38 (3.99) cm; wt: 83.31 (4.66) kg; body mass index: 30.38 (0.83) kg m^{43})

The results of the study was that the CG showed no improvements in body composition or MS parameters(MSP). The WSG showed improvements only in HDL Cholesterol(14.24 (16.13) $mgdL^{-1}$, P<.05). The WEG exhibited significant improvements in terms of hip circumference and visceral fat area(VFA) (-2.28 (3.27) cm and -13.11 (9.83) cm^2, respectively, P<.05); ; high-density lipoprotein cholesterol (HDL-C), fasting glucose (FG), and triglycerides (TG) (16.36 (8.39), -2.53 (3.73), and -10.52 (36.26) $mgdL^{-1}$, respectively, P<.05). The study concluded that the combination of a walking EP and daily step goal is a more time efficient strategy in improving body composition and MS than simply establishing a daily step goal.

2.3.3 Pilot Studies

A Norwegian pilot study done in 2008 gathered thirty-two MS patients of age 53±3.7 years and randomized them into equal volumes of either moderate continuous moderate exercise(CME: 70% of highest measured heart rate(HMHR)) or aerobic interval training(AIT: 90%HMHR). 3 times a week for 16 weeks or to a control group.

Vo2max increased more after AIT than CME(35% vs 16%; P<0.01) and was associated with the removal of more risk factors that constitute MS. The two training programs were equally effective in reducing mean blood pressure and reducing body weight and fat. AIT was more effective in reducing blood glucose. The study concluded that exercise intensity are important factors for reverting the risk factors of MS.

2.3.4 Systematic Reviews and Meta Analyses

Published in the Cardiovascular Diabetology Journal, a 2017 systematic review and meta analysis was done on the effects of aerobic exercise training on clinical outcomes in patients with the MS.[Ostman et al., 2017]. The review includes 16 different studies with 23 intervention groups and 77000 exercise hours in total.

The results of the review was that waist circumference was significantly reduced

MD −1.37 cm (95% CI −2.02, −0.71, $p < 0.0001$). Systolic blood pressure and diastolic blood pressure were significantly reduced, MD −2.54 mmHg (95% CI −4.34, −0.75, $p = 0.006$), and, MD −2.27 mmHg (95% CI −3.47, −1.06, $p = 0.0002$) respectively. Fasting blood glucose was significantly reduced MD −0.16 mmol L−1 (95% CI −0.32, −0.01, $p = 0.04$). Triglycerides were significantly reduced MD −0.21 mmol L−1 (95% CI −0.29, −0.13, $p < 0.00001$). Low density lipoprotein(HDL) was significantly reduced MD −0.03 mmol L−1 (95% CI −0.05, −0.00, $p = 0.02$). The study concluded that exercise training improves metabolic outcomes in people with MS.

2.3.5 Effect differences on gender and age

One of the studies included in [Carroll and Dudfield, 2004] found that among 621 African American and Caucasian sedentary participants, there were no sex or race differences in the efficacy of exercise in treating MS.

2.4 Artificial Intelligence

This section covers the background knowledge needed to understand the basics of how AI is used in this work. AI is the ability of a digital computer to perform tasks commonly associated with intelligent beings [Russell and Norvig, 2020]. The term is frequently used in the process of developing systems with intellectual processes such as the ability to reason, discover new things, learn from past experiences and apply knowledge obtained in creating new solutions, effectively attempting to mimic human reasoning.

2.4.1 Evolutionary Algorithms

Evolutionary Algorithms(EAs) are heuristic search methods based on Charles Darwin's theory of natural evolution[Floreano and Mattiussi, 2008]. EAs are very useful for finding near optimum solutions of complex optimization problems. They are easy to process in parallel and have the ability to escape from local minima where other methods may fail. EAs are capable of handling multi object optimization without any dataset or gradient til build upon. EAs are appropriate for problems with stochastic characteristics, uncertainties or fitness with noise.

2.4.2 Genetic Algorithm

The GA is an example of such an evolutionary algorithm[Floreano and Mattiussi, 2008]. The GA is a metaheuristic inspired by the process of natural selection. The GA is commonly used in search and optimization problems in computer science. The algorithm uses steps of natural selection as in biology. An initial population of candidate solutions to a problem called chromosomes is created, and the fittest chromosomes of the population have the highest chance of creating offspring solutions. These new solutions are subject to mutation, that is; change, in some way. The new solutions are then added back in to the population and the process is repeated until a solution in the pool of solutions meets a certain criteria, like being good enough or being in convergence to an optimal solution. Each of these steps of the algorithm is explained in more detail below.

Initial Population

An initial pool of chromosomes are randomly generated. Each chromosomes is a potential solution to a problem you are trying to solve. A chromosomes is characterized by a set of parameters known as genes. These genes join together to form the chromosome. The genes in a chromosome are typically encoded as a string of binary numbers. Table 2.4 displays an example of four arbitrary, distinct candidate solutions modeled as chromosomes which each have a string of six genes.

	Chromosome					
C1	0	0	1	1	0	0
C2	1	1	0	0	1	1
C3	1	0	1	1	1	0
C4	0	1	0	0	1	0

Table 2.4: Initial population

Fitness Test

After the initial, random, chromosome generation, and after each generation of the algorithm adds to the population, a fitness test is executed. This fitness test is designed to evaluate the fitness of each individual chromosome in the population. The fitness test returns a score for each chromosome based on how well it performs in the fitness test. This fitness test differs for each kind of problem the GA is used for. In its essence, the fitness test evaluates how well suited a chromosome is to solve a problem. Table 2.5 shows us the the candidates from before with fitness scores added. Note that these scores have been added at random and is not based on the genes of the chromosome in this example.

	Chromosome						**FS**
C1	0	0	1	1	0	0	76
C2	1	1	0	0	1	1	54
C3	1	0	1	1	1	0	89
C4	0	1	0	0	1	0	91

Table 2.5: Fitness Test

Selection

The selection phase of the GA selects the fittest individual chromosomes in the population by their fitness score after the fitness test. The idea is that the fittest chromosomes of the population should be the ones to crossover and produce new offspring chromosomes. The higher the fitness the score, the higher the chance of being selected as parent chromosomes for new offspring chromosomes. Table 2.6 shows that the selection stage has chosen two of the chromosomes as parent chromosomes.

	Chromosome						FS
C1	0	0	1	1	0	0	76
C2	1	1	0	0	1	1	54
C3	1	0	1	1	1	0	89
C4	0	1	0	0	1	0	91

Table 2.6: Selection

Crossover

The crossover point is a significant phase of the GA where chosen parent chromosomes come together to 'mate' and produce offspring chromosomes. The crossover point is a randomly chosen point within the genes of the parents that select how many genes should be used from each of the parent chromosomes. Offspring are created by exchanging genes of parents among themselves until the crossover point is reached. The new offspring chromosomes are then added to the population. Table 2.7 displays a crossover point between the two selected parent candidates.

C3	1	0	1	|	1	1	0
C4	0	1	0	|	0	1	0

Table 2.7: Crossover

Children are then created by exchanging the genes of the population among the two parents until the crossover point is reached. Table 2.8 displays the result of this transaction in two new children chromosomes created from the parents. These children chromosomes are added to the population. At this stage in the GA, it is also common to remove two chromosomes from the population that have low FS. This can be done by selecting the two chromosomes with the lowest FS, or by giving each chromosome a chance of being removed based on their FS, that way each chromosome has a chance of 'surviving' no matter their FS.

C5	1	0	1	0	1	0
C6	0	1	0	1	1	0

Table 2.8: Children

Mutation

The mutation stage introduces variety to the evolution of the chromosomes by subjecting the genes of the offspring to mutate with a low random probability. This can for example mean flipping a few of the bits in the chromosome string with a low random probability. Table 2.9 shows that the last two genes in chromosome C5 has been selected for mutation and the bit value of the gene has been flipped.

Before Mutation

C5	1	0	1	0	1	0

After Mutation

C5	1	0	1	0	0	1

Table 2.9: Mutation

Termination

The algorithm is terminated, meaning stopped; if the population has converged towards a solution. This means that the new offspring chromosomes created in the GA does not significantly differ from the existing chromosomes in the population. At this time, the GA has provided a solution to the problem.

2.5 Motivation

This section covers the motivation behind choosing to use the GA and the motivation behind choosing to work in the field of creating EPs for patients with MS in the context of the research goal and research questions.

2.5.1 Motivation Behind Research Questions

The task of creating EPs seemed like an interesting challenge, the problem consists of many factors that all needs to be considered in the development of an EP. Creating an EP for a person involves many different fields such as medicine, sport science and nutritional science. Combining all of this made the challenge seem ambitious but highly interesting. Choosing this as the main task of the thesis was done without the process of literature search, but rather through interest and ambition.

An interesting idea would be to create EPs for top level athletes. This would simplify the scope a bit because one could assume that the athletes would complete the workouts with high effort, and also that other important factors in exercise such as sleep and nutrition would be close to optimal. A lot of preliminary reading went in to figuring out if this would be a good topic. In the end this topic was dropped because of the perceived difficulty of testing the generated EPs on actual people in a later stage.

The next topic that was considered was creating EPs for patients suffering from different health conditions. This seemed very interesting and there was a lot of interesting research on EPs for different conditions and diseases. Though by far the most research had been done on how to help people suffering from MS and overweight and obese patients in general. Having a solid background in research, this topic was chosen to build upon for this thesis.

2.5.2 Motivation Behind Genetic Algorithm

The GA was chosen because out of all the evolutionary algorithms, it seemed like the best fit for the research goal of the thesis. The problem being to cure or get close to curing MS for a patient can be seen as multi object optimization problem where several health parameters have to be improved in order to solve the problem, there is also another objective of making the EPs simple to understand and easy to follow meaning there should be as little effort as possible required from the patients in performing the EP. This is because patients with MS generally are not able to perform more than a minimum amount of exercise. In total this adds up to many factors that have to be considered and balanced in order to find a balanced solution.

For this reason, the GA was chosen for its merits on multi object optimization and ability to find new solutions by escaping local minima that other potential methods could not. Creating EPs with the GA also allows the EPs to continuously evolve and change dynamically over time to better suit the continuously updated health status of the patient. One of the most important benefits of using the GA or AI in general is that each patient with MS can receive their own personal EP tailored specifically to improve their health condition the most at the lowest possible effort. This is very important as having an EP that requires too much effort could potentially make the patients lose motivation and stop exercising.

2.6 State of the art

This section includes some of the most relevant and recent research done on the subject of creating EPs for people suffering from metabolic diseases and how AI has been used to create EPs for them. There has not been done much is this research area before. The state of the art is therefore largely based on how AI has been used to solve similar problems and how traditional EPs typically have been made for people with metabolic diseases.

2.6.1 Creating exercise programs for people with metabolic diseases

The problem of creating EPs for people suffering from MS is not an easy problem to solve. In its essence, the main goal is to lose weight, but simple does not necessarily mean easy. The EP must be tailored to the persons medical history and individual. The main goal is to improve the health parameters that make up the definition of having MS. This section investigates the most efficient, simple and researched ways to achieve this goal and create EPs that lets the patients reduce their chances of illness from MS.

The paper [Støa et al., 2020] researched the role of exercise and physical activity on weight loss and the maintenance of weight loss. It was found that performing exercise training, regardless of weight loss provides numerous health benefits. This was especially true for overweight and obese people. The main benefit was that the risk of cardiovascular diseases were dramatically reduced even if the weight did not go down. As cardiovascular disease is one of the main concerns for patients with metabolic disease, this research shows the importance of exercise to combat metabolic disease.

The positive effects of exercise is further backed up by[Berge et al., 2021]. This study investigated the effects of aerobic exercise intensity on energy expenditure and weight loss in severe obesity. The study also found that for patients with severe obesity, a combination of high intensity interval training and moderate intensity continuous training expended more energy during exercise than patients who did just HIIT. The patients who did MICT also lost on average 3kg more body weight over the 24 week study period.

2.6.2 Artificial Intelligence for Exercise Programs

Creating EPs is a skill that requires many different areas of expertise. The program must be sufficiently demanding to the human body to force growth in the targeted areas. Whether the goal of the program is to increase cardiovascular ability, strength, hypertrophy, lose weight or increase health status, the individual exercises of the program must be well though out. This can be seen as a multi objective challenge that should be a fitting problem for an evolutionary algorithm to solve. Unfortunately, there has not been done much research on this area. This thesis therefore includes a few examples on how AI has been used in the fitness and exercise industry to give an idea what AI is cabable of.

Applications of AI in Exercise

This section contains examples of how AI has been used in the development of a few EP applications. While these examples differ slightly, they are all based on machine learning with a large dataset of exercises previously performed. This dataset feeds a neural network the data needed for the machine learning algorithm to learn from the previous exercises to suggest new EPs.

FitnessAI FitnessAI is an application for smartphones that uses artificial intelligence to generate personalized workouts based on a dataset of 6 million workouts. The application optimizes sets, repetitions and weights for each exercise every time a new workout is performed.

Aaptiv Coach Aaptiv coach is another ai based personal trainer created by Aaptiv. The workouts are highly personalised based on individual goals, current fitness levels, eating habits and data obtained by fitness trackers such as smartwatches.

Fitbod Fitbod provides highly personalized workouts based on continuously evolving exercise plans. Fitbod uses a series of algorithms and machine learning to calculate workout volume and intensity, depending on past workouts, to maximise results.

As seen, creating EPs is already an application area of AI. Mainly by the use of machine learning algorithms. Creating EPs from evolutionary algorithms such as the GA has not yet been done.

2.6.3 Similar Problem Domains

As there has not been done much work in field of research done on creating EPs by using AI, one can instead take a look at how AI has been used to solve similar problems to creating EPs.

A similar problem is one that has many objectives it wants to maximise in order to achieve one bigger goal. [Monsefa et al., 2019] conducted research on multi objective optimization algorithms to water distribution network optimum design. Three different approaches were explored and the conclusion was that Multi-objective differential evolution(MODE) generally gave the best results both in terms of converging speed and IGD.

[Gunantara, 2018] did a review on multi objective optimization methods and its applications. The paper finds that the are many methods in solving multi objective optimization. The conclusion found was that there are two methods that do not require complex mathematical equations, namely the Pareto and scalarization methods. The Pareto method has dominated and non dominated solutions. The scalarization method creates multi objective functions into a single solution.

Chapter 3

Model

This section will cover the methods used for the implementation of a simulator using the GA. To simulate the effects exercise has on patients, an exercise simulator has been created to be able to simulate the patients doing the exercises and find the resulting health parameter changes on the patient. The GA is implemented with this exercise simulator as its fitness test. The GA itself has been implemented very similar to the textbook way of implementing a GA as seen in 2.4.2. The way this implementation of the GA stands out is in its fitness test complexity as can be read in detail in 3.4.2. Chart 3.1 illustrates the steps in the GA and simulator.

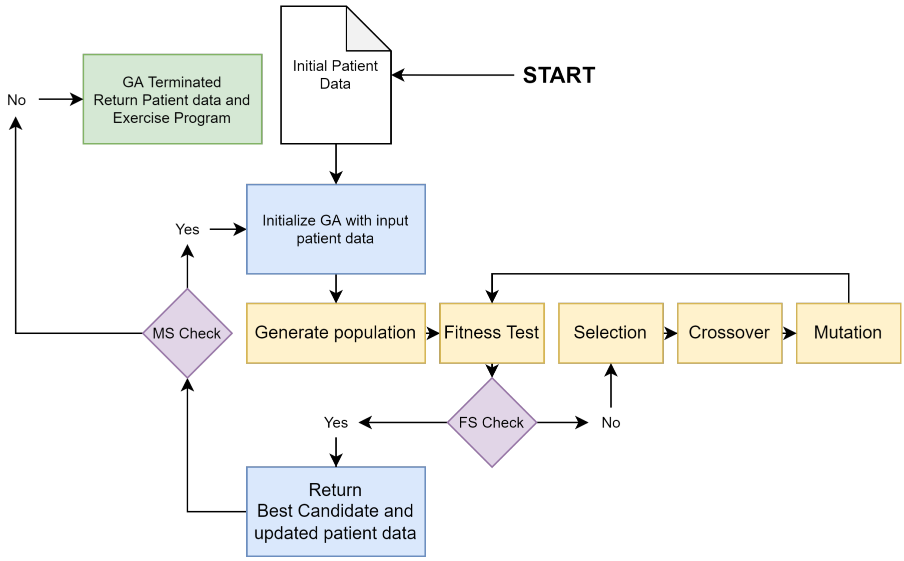

Figure 3.1: Overview of the Simulator

3.1 Brief Simulator Overview

As can be seen in figure 3.1, the GA initializes with a patients data as input. A population of 20 random candidate EP of eight weeks are then generated. Each program is tested through a fitness test(FT) to see how well it is able to improve the patients health parameters resulting in each of the 20 EP's receiving a fitness score(FS) based on the results of the fitness test. After the FT, a FS Check is performed to see if one of the candidate EPs has received a good enough score to be selected as a solution by the algorithm.

If it was not, the algorithm chooses two of the best EPs are parent EPs in the selection phase and creates new children EPs based on those in the crossover phase. Two of the worst EPs are also removed. The new children EPs are then subject to a small mutation with a low random probability. Then, the pool of candidate EPs are subject to a new FT. If the FS Check says the EP is good enough, the algorithm returns it as a solution EP for the problem.

Whenever the algorithm returns such a solution EP, an MS Check is performed to see if the solution EP is able to cure MS. If it is, the algorithm stops and returns this EP as the final solution. If it isn't, the simulation still runs the patient data through this solution EP to get closer to being rid of MS. After this the simulation is started again with a new period of eight weeks of exercise, but this time; it starts with the updated patient from the previous eight weeks.

These periods of eight weeks can be simulated as many times as needed until the patient is rid of MS, and realistically, it has to be run as long as they live for the patient to stay rid of MS.

3.2 Human Model

As mentioned in section 3.1, the GA takes human health parameters as input data. This input data is a simple way to model a human being by just the parameters needed to see if they have MS or not, and a few other parameters needed for the exercise part of the simulator, namely the humans capability to walk, jog and run(W,J,R) and their motivation to comply with the EP.

Table 3.1 shows an example of a patient with a few health parameters that can tell whether the person is defined as having MS or not. As seen in section 2.1, the person needs to have three out of the five health parameters out of of the normal range to be defined as having MS. This example person has four out of the five parameters out of normal range(red) and is therefore in the definition. In the table, Gen = Gender, Trig = Triglyceride, Chol = Cholesterol, Cir = Circumference, Mot = Motivation, Cap = capabilities(W = Walk, J = Jog, R = Run).

Health Param	**Gen**	**BP**	**Trig (mg/dl)**	**Blood Glucose (mg/dl)**	**HDL Chol (mg/dl)**	**Waist Cir (cm)**	***Cap (W,J,R)***	***Mot 0-100***
Status	M	120/70	160	120	42	116	WJ	90

Table 3.1: An example human with health parameters

This work includes two versions of the human model, a basic one and an advanced one. The basic human model only uses the five health parameters needed to see if the patient has MS. While the advanced model also includes the patients motivation to comply with the EP and their capability to perform the exercises. Some patients may only be able to do walking exercises while others can also jog or possibly even run.

3.2.1 Energy Balancing

Whilst energy is not one of the parameters included in the human model used in the test, it was an added parameter used in the simulator to balance out how much exercise a human should be able to do before having to rest. Early testing without energy as a parameter in the simulator made the humans capable of doing unrealistic amount of exercise, for that reason, an energy balance was introduced. Every time an exercise is about to be executed, the simulator checks whether the patient has enough energy to do the exercise, if it does not, the exercise is not executed and the patient rests. If the patient has enough energy, the exercise is performed and the energy of the patient is drained. Each patient started every day with 100 energy, and each exercise drains the energy according to equation 3.1 that takes in the intensity, duration and type of exercise and returns the energy cost of the exercise. The typemodier is 0 for walking, 10 for jogging and 20 for running. This is done to differentiate the energy cost of the three exercises based on how taxing they are. the typemodifier constant in the equation is 0 for walking, 10 for jogging and 20 for running, section 3.3 explains the reasoning behind this.

$$\Delta Energy = \frac{(Intensity + typemodifier) * Duration)}{10} \tag{3.1}$$

3.2.2 Motivational Balancing

Motivation can have a huge impact on whether or not a patient is able to complete an EP or even a single exercise as seen in 2.2. If the proposed exercise is too taxing, the patient may find it disheartening and choose not to complete it only partly do so. Being able to complete the exercises can also be a big motivational factor that may help the patient succeed in becoming healthier. For these reasons, a motivational balance is also implemented in the advanced version of the human model. Similar to how energy is modelled, the patient starts out at a certain level of motivation to rid themselves of MS by exercising. Every time an exercise is about to be done, the simulator checks whether they are motivated enough to attempt the exercise. If the motivation is high, they will complete it, if it is moderately high, the patient may complete it, only partly complete it or not even attempt at all. If the motivation is too low, the patient will not do the exercise. After each exercise, the patients motivation will be adjusted according to the results of the exercise.

Limitations of Human Model

To get completely realistic results from the simulator, the model of the humans in the simulator would have to be accurate models of human beings. This would include modelling of every organ, every limb and more. This is not realistic within the scope of this thesis and may not be realistic to model at all. The simulators ability to produce realistic results is therefore based on the assumption that this human model, advanced or not, contains enough information. Building upon this model to make it more realistic is further explored in section 5.3.

3.3 Exercise Program Model

One of the key concepts of this work is how the EPs are modelled. For the algorithm to run fast and not take up too much memory the EPs have to be modelled in such a way that it contains all the necessary information in a compact way. These EPs only include the cardiovascular exercise of walking, jogging and running. Each of these exercises can be performed every day of the EP, even if the other exercises are also done on that that. The three exercises each include two parameters: the intensity of the workouts(1-10) measured in heart rate. Note that the intensity of jogging starts off where walking ends, meaning that intensity 1 for jogging is intensity 11 overall, the same applies for running which starts off where jogging ends. As an example, running at intensity 5 is intensity 25 overall. The total intensity range of the exercises is then 0-30. The EP also includes the duration of the exercises in minutes from 0 to 1440. Having the possibility of workouts being as long as 1440 minutes may seem extreme, but this is important to allow the evolution part of the algorithm the freedom needed to explore all possible solutions. An example of an EP can be found below in table 3.2. Unless otherwise specified, the term 'EP' is always used to describe the planned exercises for one week for a patient.

Walking			**Jogging**			**Running**		
Int	*Min*	*Days*	*In*	*Min*	*Days*	*In*	*Min*	*Days*
5	20	[1,0,1,0,1,0,0]	3	15	[0,1,0,1,0,1,1]	7	10	[0,0,0,0,0,0,1]

Table 3.2: Example of a Weekly Exercise Plan

Row three in table 3.2 illustrates exactly how the EPs are modelled in the implementation of the GA, with rows one and two added to show what each number in row three mean. Int = intensity and min = minutes. The days string of 1 and 0 represents each days of the week where 1 means do the exercise and 0 means do not do the exercise. To make it clearer what the program actually is, table 3.3 takes the program from table 3.2 and splits it in to days of the week.

	M		**T**		**W**		**T**		**F**		**S**		**S**	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	*20*	*5*	*20*	*5*	*20*	*5*	*0*	*0*	*20*	*5*	*0*	*0*	*0*	*0*
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Table 3.3: Example of a weekly exercise plan

Table 3.3 is closer to what the program would actually look like should it be given to a real person for exercise. The columns shows each day of the week and the intensity and duration of each exercise for that day. Note that when intensity and duration are both 0, it means that the person should not do that exercise that day.

Limitations of Exercise Program Model

The EPs are limited to only three types of cardiovascular exercise, namely walking, jogging and running; as previously seen. Having more types of cardiovascular exercise such as biking or swimming or even different types of exercise like strength training would introduce more novelty, more options for the patient and more options for the evolutionary process to find alternative solutions, but this is outside the scope of this thesis. Section 5.3 explores other possibilities. Also as seen in section 2.3, the exercise regimens used to treat MS mainly contains walking, jogging and running.

The EP is also limited to only one of each type of exercise per day, for example it can only have one walk per day. The workouts are also always performed in the order of walking first, then jogging, then running. This is done to make it simpler for the person executing the program to follow it. After all, it is vital that the programs are easy to understand to allow for the best chance of actually going through it and achieving the wanted results.

3.4 Implementation of Genetic Algorithm

This section will describe how this implementation of the GA differs from the classical way of using the GA as was seen in 2.4.2. In short, it is implemented in a very similar way, except for the complexity of the fitness test and the possibility to do several runs of the algorithm to simulate several exercise periods.

Model knowledge

The GA itself does not need any previous data to build upon. The initial pool of chromosomes(EPs) are generated randomly and the future generations are built upon this. The fitness test within the GA however, has access to a set of patient data to evaluate which EP's can improve the health parameter status of each patient in the most efficient way.

3.4.1 Random Population Generation

The GA initializes by creating a few randomly generated EPs. By default the amount is twenty, but this can be specifically set in the simulators settings. Each EP is a weekly program consisting of three different types of cardiovascular exercise: walking, jogging and running. Every day of the week can contain zero(resting day), one, two or all three of these. Each exercise done consists of an intensity(HR) and duration(minutes). Whenever a EP is created, the intensity and duration of each type of exercise is the same for that exercise for every day of the program. As an example: if jogging is set to be 20 minutes at intensity 5, jogging will stay that way for the entire duration of the program. The values of intensity, duration and which days the exercises should be done are completely random within the boundaries of each parameter as seen in 3.3

As was seen in table 3.2, a program consists of a weekly plan. The 'Days' columns tell us which days the different exercises should be done. Some days may contain just walking, while others contain all three or none of them, which would be a resting day. In total a person goes through eight of these weekly EP's before the health status of the person is measured and therefore the fitness score of the EP is calculated.

3.4.2 Fitness Test

The fitness test is designed as an exercise simulator that runs each EP on a test human in a Simulated Exercise Period(SEP) and attempts to make the human healthier by simulating exercises. After the SEP is complete, each EP will receive a fitness score based on how well it performed in the FT for further use in the GA.

Simulated Exercise Period

As seen in the brief overview of the model in 3.1, the fitness test is designed as an eight-week training period where the patient is given a candidate exercise program. Every week is designed to be exactly the same. This is done do make the program simpler to follow for the patients. Each of these eight weeks consists of seven days of potential exercise. Each day can contain one of each type of exercise(Walk, Jog and Run). This means the program can consist of anything between 0 and 21 exercises each week, or between 0 and 168 exercises each eight-week period. Of course, the ideal amount would not be anywhere close to these minimum and maximum numbers, but they are set as such to allow the evolutionary process the freedom the explore any possible solution.

Every time an exercise is done, the metabolic parameters of the test human doing the exercise are changed. This means the values can be changed from 0 to 3 times a day depending on how many exercises are done. Over the course of a week this leads to the MS parameters being changed many times. Of course, in the real world; these parameters continuously change all the time in the human body. The image below 3.2 illustrates a potential day of exercise, as can be seen; the metabolic parameters are readjusted after each exercise and returned at the end of the day. Beginning the next day, the parameters for the last day are used as the starting point.

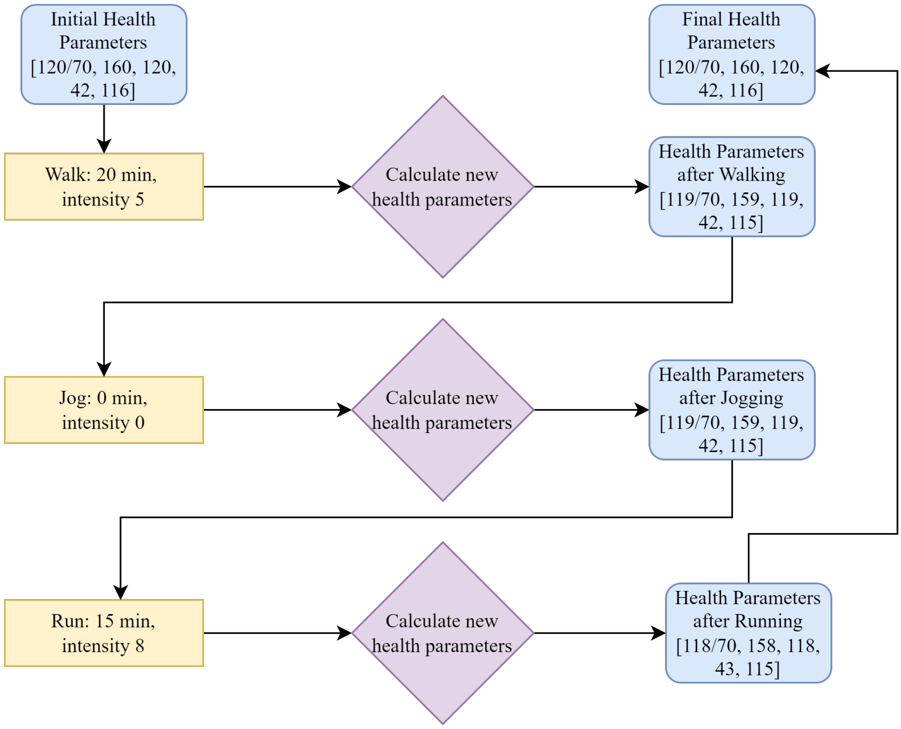

Figure 3.2: A day of exercise

After the eight-week program is complete, the MS parameters of the human is evaluated and the EP is given a fitness score based on how well it performed in changing the metabolic parameters of the test human.A good fitness score(FS) is given to an EP that manages to make the test human rid themselves of the definition 'MS' or get closer to it than other EPs did. That means no longer having three out of the five conditions that define it. A good program also means getting rid of this definition at the lowest possible cost of effort in the test human. This is an optimization problem that wants to get the most result from the least amount of effort. Even if the EP does not manage to rid the patient of MS, it will get a good score for getting close to it. The FS is also dependant on how taxing the EP is, this means that the total amount of benefit from the program is divided on the total effort put in, which gives the final FS. This process is run on each EP in the pool for a total of 20(unless otherwise specified) simulated exercise periods to give each EP a fitness score. An example of an eight-week program can be found in the Appendix 5.1. An overview of the fitness test can be seen in table 3.3

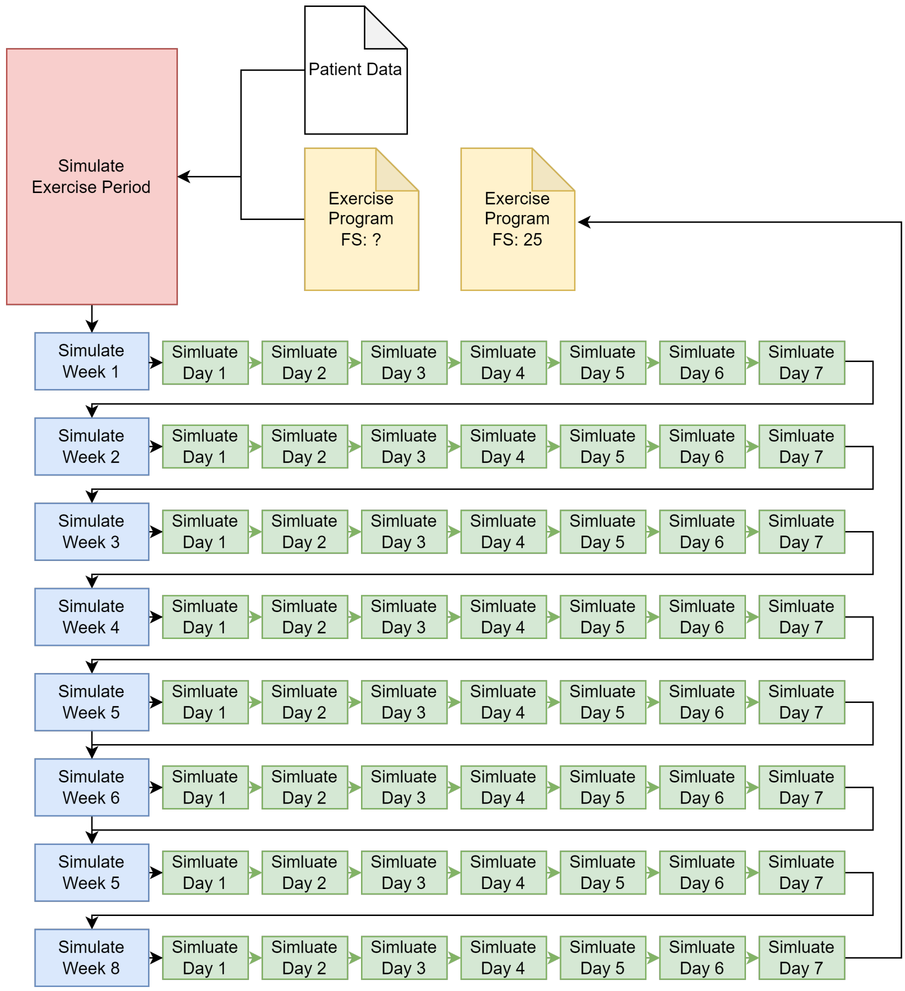

Figure 3.3: Overview of an 8 week exercise period

Scoring

Each EP adjusts the patients metabolic health parameter by a certain amount. The exact adjustments can be read about in section 3.5. The EPs are given a FS based on how much improvement they gave the patients metabolic health parameters.

3.4.3 Fitness Score Check and Metabolic Syndrome Check

After each candidate EP has been given a FS, a FS Check is done. This checks whether any of the candidate EPs has reached a high enough FS. The exact number is set to be the point where the candidate solutions converge towards similar solutions. It is assumed that this convergence point will not be improved given more iterations of the algorithm.

If this is so, the candidate EP goes through a MS Check which checks whether the EP is able to rid the patient of MS, if so, the simulation is complete and a solution has been found. If not, the simulation is started over again, but this time the initial patient data is replaced with the resulting patient data from the already done eight-week program. If the FS Check returns no EP with a high enough fitness score, the algorithms continues on to the selection phase.

3.4.4 Selection

The selection phase of the GA selects the fittest individual EP's in the population by their fitness score after the fitness test. The idea is that the fittest individuals of the population should be the ones to crossover and produce new offspring. The higher the fitness the score, the higher the chance of being selected as parents for new offspring. The selection is implemented as a Roulette Wheel Selection. This means that each EP is in the pool is given a portion of a roulette wheel proportionate to their fitness score. The roulette wheel is then 'spun' and the program it 'points to' is selected as the parent. This is done twice to select two (distinct) parents.

3.4.5 Crossover

The crossover point is a significant phase of the GA where the chosen parent EP's(chromosomes) come together to 'mate' and produce offspring EP's. The crossover point is a randomly chosen point within the genes of the parents that select how many genes should be used from each of the parent EP's. Offspring are created by exchanging genes of parents among themselves until the crossover point is reached. The new offspring EP's are then added to the population. In this implementation, parent EPs can crossover pairs of exercise stats meaning that if for instance the walking exercise from one parent is chosen, it will take both the duration and intensity of the exercise and not just one of them. The days of the exercises are also subject to crossover at a randomly chosen crossover point.

3.4.6 Mutation

The way mutation is implemented is as follows. First, a child EP is subjected to mutation with a low random probability. Then, again, with a low random probability, the different exercises within each child EP is chosen whether to be mutated or not, between none and all of the exercises can be chosen. The chosen exercises is then, again at random, chosen whether to mutate the duration, intensity or days of the exercise. If duration is chosen, the duration will be expanded or shortened by anywhere from zero to ten minutes. If intensity is chosen, it will be adjusted up or down by one. The mutations are designed to be small to mimic real evolution. If days are selected for mutation, each day is changed to either having exercise or not with a 50/50 chance.

3.4.7 Termination

The termination stage of the GA stops the GA from running when a certain condition is met; that is, when the fitness score of an EP reaches a certain fitness threshold. When this condition is met, the EP that reached this level of fitness is selected as the final EP. To reach this fitness threshold, the EP's have to be converging towards a solution to the optimization problem that is improving the patients health. As mentioned in section 2.1 the definition of having MS is having three out of the five following:

- **Abdominal obesity**: a waist circumference over 102 cm (40 in) in men and over 88 cm (35 inches) in women
- **Serum triglycerides**: 150 mg/dl or above, or taking medication for elevated triglycerides
- **HDL cholesterol**: 40mg/dl or lower in men and 50mg/dl or lower in women
- **Blood pressure**: 130/85 or above (or taking medication for high blood pressure)
- **Fasting blood glucose** 100 mg/dl or above

The fitness test of the GA includes a model of a human with these parameters that are continually adjusted throughout the simulated exercise period of the fitness test. Whenever the candidate EPs in the GA are converging towards similar results in health parameter changes, the fitness score of that EP will meet the criteria of being selected as the solution.

3.5 Calculating Health Parameter Adjustments

Arguably one of the most important parts of simulating exercises is calculating mathematically how much the the exercises impact the patients health. To be able to compute the effects on health parameters in a simulated exercise environment, realistic and mathematically sound equations are needed. Of course, as stated in 1.3, this can not be modelled in a completely realistic way, there are simply too many factors to consider which are outside the scope of this thesis. Hence, the following equations are simplified versions of the effects on the metabolic parameters of a human based on the type of exercise and the duration and intensity of the exercise.

Building upon the knowledge gained in section 2.3, every time an exercise is executed, for example walking for 30 minutes at intensity 5, all of these equations are called to compute the changes in the each health parameter for that exercise. The parameter α is used as the total intensity of that exercise. By total intensity it is meant the intensity of the exercise plus an additional ten for jogging and twenty for running. As an example this means that the total intensity of jogging at intensity 5 is 15, this is done to differentiate the intensities of the three possible exercises. The duration of the exercises is defined as β in the equations.

The equations include some local parameters used for each health equation type. These abbreviations can be seen in table 3.4. The health parameter modifiers in the table defines constants for each health equation which are used to differentiate how much the intensity of the exercises impacts the changes in each health parameter. Some parameters change more or less than others at lower and higher intensities, which is why these constants are needed. The change in health parameter modifier constants has two purposes, firstly they are needed to differentiate how much each health parameter changes as they are not equal. Secondly they are used to scale the changes in all parameters as a whole.

	Health Parameter Modifier		**Change in Health Parameter Modifier**	
Health Parameter	**Abbreviation used in equation**	**Value**	**Abbreviation used in equation**	**Value**
Systolic BP	BPSMod	0.00	CBPSMod	400
Diastolic BP	BPDMod	0.00	CBPDMod	400
HDL	HDLMod	-0.01	CHDLMod	1600
Waistline	WaiMod	0.00	CWaiMod	2000
Triglycerides	TriMod	-0.02	CTriMod	300
Blood Glucose	BGMod	0.00	CBGMod	1000

Table 3.4: Abbreviatins used in health parameter equations

Systolic Blood Pressure Equation
$\Delta BP = BP * (1 - (\frac{\delta^2}{\delta + BPSMod})/CBPSMod) * \beta$

Diastolic Blood Pressure Equation
$\Delta BP = BP * (1 - (\frac{\delta^2}{\delta + BPDMod})/CBPDModr) * \beta$

HDL Equation
$\Delta BP = BP * (1 - (\frac{\delta^2}{\delta + HDLMod})/CHDLMod) * \beta$

Waistline Equation
$\Delta BP = BP * (1 - (\frac{\delta^2}{\delta + WaiMod})/CWaiMod) * \beta$

Triglyceride Equation
$\Delta BP = BP * (1 - (\frac{\delta^2}{\delta + TriMod})/CTriMod) * \beta$

Blood Glucose Equation
$\Delta BP = BP * (1 - (\frac{\delta^2}{\delta + BGMod})/CBGMod) * \beta$

Chapter 4

Experiments and Results

This chapter describes the tests and results from the model used in this project. The tests aim to answer the research questions as presented in 1.2 A number of different tests were used in the implementation of the GA and to test the simulator during and after its completion. The tests can be divided into those used during the development to make sure the final implementation was sound, and the tests performed on the final implementation of the simulator to answer the research questions.

4.1 Experimental Plan

The experimental plan gives an overview of the tests used in this work and how they relate to the research goal and research questions. The test plan shows which tests were utilized and for what purpose. It also describes how the data was gathered to produce results for later analysis.

Preliminary Tests

Table 4.1 presents the preliminary tests used in the development of the GA and simulator. Note that these preliminary tests were fairly small. The preliminary genetic algorithm tests were used test if the selected strategies for the selection, cross and mutation stages of the GA was sound. The preliminary simulator optimization tests were used to balance the energy and motivation of the patients in the simulated exercises.

Test Number	**Test Name**
Preliminary Genetic Algorithm Tests	
PGAT 1	Selection Strategy
PGAT 2	Crossover Strategy
PGAT 3	Mutation Balancing
Preliminary Simulator Optimization Tests	
PSOT 1	Energy Balancing
PSOT 2	Motivational Balancing

Table 4.1: Preliminary Test Plan Overview

Experimental Tests

Table 4.1 gives an overview of the experimental tests used to produce results aimed at answering the research questions. The experimental tests are split in to two phases, testing with the simple human model(SHM) and the advanced human model(AHM). Each of these phases has two tests, one for creating and performing an 8 weeks program for the patients, and one for continued exercise after the first period is over.

Test Number	**Test Name**
Phase 1: Simple Human Model	
Experimental Test 1	Initial Exercise Period
Experimental Test 2	Secondary Exercise Period
Phase 2: Advanced Human Model	
Experimental Test 3	Initial Exercise Period
Experimental Test 4	Secondary Exercise Period

Table 4.2: Experimental Test Plan Overview

4.1.1 Data Gathering and Results

When the simulator is run, the GA runs through many generations in order to find solutions. For each generation, the best candidates fitness score is saved in a list. After the GA finds a solution by creating an EP with a high enough FS, the candidate EP that received this FS is saved as the final EP that should be executed by the patient. The health parameter changes on the patient from executing this EP is also saved. This data is used to build two types of results: grouped bar graphs showing changes in health parameters and tables showing EPs. This data was further used to create more tables that have been used in this chapter.

4.1.2 Testing Environment

The testing environment was the simulated exercise period where a patient had to execute an EP in order to improve their health status and potentially rid themselves of MS. This period was set to eight weeks, which could be repeated with updated health parameters and a new EP for each eight-week period. The differences in the testing environment came from the patients ability to walk, jog and run which would create different EPs for each specific patient.

4.2 Preliminary Tests

The preliminary tests were small experiments performed during the development of the GA and Simulator. This section contains information on which strategies were chosen for some selected steps in the GA. Further, some explanation of how energy and motivation balancing were implemented is provided.

4.2.1 Genetic Algorithm Implementation Tests

In the GA, there are numerous steps as read in section 2.4.2. Each one of these steps can be implemented in slightly different ways. The tests performed here were aimed at figuring out what strategy to use on each of the these steps in the GA.

PGAT1: Selection Strategy

As read in section 3.4.4, the selected strategy for choosing which parent EPs should be the ones to crossover and create new children EPs is Roulette Wheel Selection(RWS). During development there was also an alternative way of choosing the parent EPs, namely selecting the two candidate EPs with the highest FS. Both versions were tested thoroughly and RWS was chosen because unlike simply choosing the best ones, RWS gives all candidate EPs a chance of being selected which introduces more potential solutions to explore and also decreases the chance of having the GA end up in a local minimum or running endlessly.

PGAT2: Crossover Strategy

In order to find the best way to crossover from the chosen parent EP to new children EPs, several possible ways were explored. The first strategy that was considered was one-point crossover which simply picks a random crossover point between the two parent chromosomes. This would not work as the genes i the chromosomes modelled in this thesis have very specific positions in relation to each other. Randomly crossing over the genes would ruin chromosomes.Next, two point and uniform crossover strategies were considered, but they shared the same problem of one-point crossover, crossing over at random points would ruin the links between the genes in the chromosomes. It was decided that a position based crossover operator could work, with this, some pairs of genes in the chromosome could be selected to crossover together as a tuple. Pairs of genes like intensity and duration of an exercise would no longer be broken by a random crossover point. As such, position based crossover with pairs of genes was selected as the crossover strategy.

PGAT3: Mutation Balancing

The challenge with mutating the chosen children EPs came down to how large the mutations should be allowed to be. Whilst allowing big mutation introduces more variety in the gene pool, it can introduce too much randomness in the GA. A Test was performed to find a balance between too much and too little mutation.

The chosen variation randomly gave the each exercise in the EP a 1/10 chance of mutating. If they were selected to mutate, there was a 1/3 chance of mutating either the duration, intensity or days of the exercise. If duration was chosen, it was increased or decreased by a random number from 0-10. If intensity was chosen it was increased or decreased by a random number between 0-2. If days were selected, each day was flipped from having exercise to not having exercise or the other way around with a random chance of 50%.

Other tested versions was based on the same idea, but with different random chances for each exercise being chosen and smaller or bigger mutations to the duration and intensity. While some proved interesting, the chosen variation was selected because it introduces just enough variety to keep the GA from running into local minima which was enough. More variation and randomness would not likely lead to more scientifically significant results.

4.2.2 Simulator Optimization Tests

When building the GA around the simulator to simulate performing the exercises, several adjustments and optimizations were needed. The simulator optimization tests were aimed at balancing different parameters in order to allow the GA to produce realistic EPs and the simulator to output realistic changes in health parameters.

PSOT1: Energy Balancing

The energy balance of the patients is kept as an equation that calculates how draining an exercise is. Several iterations of this equation was tested before the one previously shown in section 3.2.1 was chosen. A balanced equation that let the patient exercise a fair bit, but not too much was needed. Simplicity was also priority in creating the equation. The obvious parameters of the equation was Intensity and duration, but it also needed a way to differentiate the energy cost of each type of exercise. A few versions of the equation were created and tested. In the equation, the typemodifer constant is 0 for walking, 10 for jogging and 20 for running.

$$\Delta Energy = \frac{(Intensity + \frac{typemodifier}{0.75}) * Duration)}{10} \tag{4.1}$$

Figure 4.1: Energy Balance Equation 1

$$\Delta Energy = \frac{(Intensity + typemodifier) * (Duration * 0.9)}{10} \tag{4.2}$$

Figure 4.2: Energy Balance Equation 2

$$\Delta Energy = \frac{(Intensity + typemodifier) * Duration)}{10} \tag{4.3}$$

Figure 4.3: Energy Balance Equation 3

After testing equation 4.1, it was shown to produce results that did not differentiate the exercises enough. The idea behind this equation was to make the type of exercise less significant. The resulting energy costs were too similar for exercises that are different. Adjusting the value of 0.75 to something closer to 1 gave better and better results which is the reason this equation was not chosen. Testing equation 4.3 gave similar results, the idea here was to give the duration of the exercise less importance, but again, the results did not support this idea. By making the duration less important, the intensity and type gained more weight, this resulted in the GA creating EPs with less importance on the duration. After realising neither of these equations were a good fit, equation 4.2 was made. This equation lays no extra weight on either the intensity nor the duration of the exercise. It is balanced and creates realistic results. Note that the patients energy was reset to 100 each new day.

PSOT2: Motivational Balancing

As read in 3.2.2, motivation considers whether or not the patient is willing to attempt an exercise. Each patient has a motivation score. Two methods of implementing motivation in the simulator were considered. The implemented method calculates how much motivation an exercise requires by using equation 4.4 and if they patients motivation score is more than what the equation suggests, the exercise is done. If the motivation is within 10% less than what the equation suggests is needed, the exercise is attempted and succeeds with a 70/30% chance. If it is within 20%, the exercise is attempted and succeeds with a 60/40% chance. If an exercise is attempted and fails, it will reduce the patients motivation by the difference between the equations suggested motivation and the patients initial motivation. If an exercise is successfully completed, it will increase the patients motivation by a static 5%.

$$\frac{(Intensity + typemodifier) * Duration}{10} \tag{4.4}$$

Figure 4.4: Equation used to calculate the motivation needed to perform an exercise

The balancing tests that went into figuring out how to balance the motivational factor of the patients against the motivation required to perform an exercise came down to a few factors. First of, creating the equation seen in 4.4. It was obvious that the equation needed the intensity and duration of the exercises as input, but also the typemodifier which lets the equation differentiate between walking, jogging and running. As with energy balancing, the typemodifier was 0 for walking, 10 for jogging and 20 for running. Further testing went into deciding the range of motivation where a person attempts an exercise and their chances of completing it. Several ranges, were tested.

Version 1 Motivation > Motivation required: Exercise succeeds Motivation within 10% less of motivation required: Exercise succeeds with a 50/50 chance. Motivation within 10-20% less than motivation required: Exercise succeeds with a 25/75 chance. Motivation more than 20% behind motivation required: Exercise is not done.

Version 2 Same as version 1 with additional features. If an exercise is failed, it will still update the patients health parameter according to the human health equations as seen in 3.5, but for each health parameter, the change will be reduced by 50%.

Version 3 Same as version 2 with additional features. Every time an exercise is completed, partially or fully, the patients motivation is subject to change. If the exercise was completed successfully, the motivation of the patient will rise relative to the difficulty of the exercise. If a patient completes an exercise where their motivation is above the required level, they will get a static increase of 0.5 motivation. If they attempt an exercise where their motivation is between 0-10% below the required level, they will get an increase in 1 if they are successful and a decrease of 1 of they are unsuccessful, for exercises within 10-20% below the required motivation, they will gain 2 motivation if they complete it and lose 1 if they do not. This is implemented to simulate the changes in a patients motivation during the course of an exercise period. Having such a dynamic motivation could allows the evolutionary process in the GA to find solution EPs that are balanced with respect to the required motivation, which is very important for patients with MS.

Version 3 was chosen for its ability to tailor the EPs for the patients with respect to a dynamically changing motivational factor. Also including the features of version 1 and version 2, it was the most advanced way to balance motivation and seemed to be the most accurate way to model motivation out of the three versions.

4.3 Experimental Tests

The experimental tests were aimed at answering the research questions. For all experimental tests, a set of patient data was used as test humans in the simulator. These test humans are modelled as explained in section 3.2. The test humans were created by Jannicke Ferger(BNurs) and quality checked by Håkon Moen(5th year medical student). There are 12 test humans in total and the these are split into six men and six women and can be found in table 4.3 for men and table and 4.4 for women, respectively. The patients are split between men and women because they do not have the same exact health parameter requirements to be defined as having MS as read in section 2.1. This also allows for some interesting comparisons between men and women.

The orange fields indicate that the health parameter is within the boundaries of MS, while the green fields means that the health parameter is within healthy ranges. The experimental tests were run both on the SHM and the AHM, for exercise periods of eight and sixteen weeks. During the simulation of their exercises, their metabolic health parameters were continually adjusted. The patients are put through two exercise periods to simulate the importance of upholding the lifestyle changes to remain rid of MS, and also to see how the updated health parameters after period one affects the EPs generated for period two.

Metric	**Range**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
General Information							
Height	>0 cm	181	189	178	190	188	187
Weight	>0 kg	104	109	94	135	102	96
Motivation	0-100	50	70	60	80	60	90
Ability	W, J, R	WJR	WJ	WJR	W	WJ	WJR
Metabolic Health Parameters							
Waistline	>101.6 cm	108	111	101	121	100	90
Blood pressure	>135/80	181/91	161/88	141/72	186/93	173/86	164/86
Triglyceride	>150 mg/dl	292	301	283	354	265	247
Blood glocuse	>100 mg/dl	147	106	124	158	115	167
HDL	<40 mg/dl	34	38	34	27	34	38

Table 4.3: Data set of test patients health parameters and other key parameters(Men)

Metric	Range	P7	P8	P9	P10	P11	P12
General Information							
Height	>0 cm	169	167	160	181	174	163
Weight	>0 kg	89	100	85	121	98	97
Motivation	0-100	60	70	90	70	40	50
Ability	W, J, R	WJ	W	WJR	W	WJ	WJ
Metabolic Health Parameters							
Waistline	>88.9 cm	102	115	88	120	96	95
Blood pressure	>135/80	142/78	171/89	169/84	173/92	135/79	151/88
Triglyceride	>150 mg/dl	168	185	194	230	159	177
Blood glocuse	>100 mg/dl	147	205	113	129	111	109
HDL	<50 mg/dl	42	34	34	42	38	46

Table 4.4: Data set of test patients health parameters and other key parameters(Women)

4.3.1 Phase 1: Simulating With Simple Human Model

Phase one of the experimental tests uses the SHM version of the patients as input in the simulator to create EPs that the patients execute. After simulating eight weeks of exercising according to each patients given EP, created by the simulator using the GA. The simulator returns the updated health parameters of the patients. The patients are then given a new EP to do based on the results of the initial eight-week EP.

Experimental Test 1: Initial Exercise Period

The first experimental test subjects the patients to an eight-week period of exercise. After the exercise period was complete, the resulting changes in health parameters were recorded. The EP created by the simulator for each patient can be seen in figure 4.5. An explanation of how to read these tables was given 3.3.

Simple Human Model: Initial Programs Men																												
	Walking									*Jogging*										*Running*									**FS**
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P1	7	31	1	1	1	1	0	0	0	7	20	1	0	1	0	0	1	1	9	19	0	0	0	0	0	1	1	5.0075
P2	9	73	1	0	1	0	0	0	1	7	1	0	1	0	1	1	0	1	8	1	1	0	1	0	1	0	0	5.0704
P3	5	124	1	1	1	1	1	1	1	10	18	1	1	1	1	1	1	0	2	2	0	0	0	1	0	0	1	5.0366
P4	2	8	1	1	0	1	0	1	1	3	54	1	1	1	1	1	1	1	3	4	0	0	0	0	1	1	1	5.3342
P5	6	86	0	1	1	1	1	1	0	3	4	0	0	1	1	1	1	0	5	77	0	0	0	0	0	0	0	6.0859
P6	4	59	1	1	1	0	1	1	1	4	48	1	1	0	1	1	1	0	2	5	0	0	0	1	0	0	1	5.5409

Simple Human Model: Initial Programs Women																												
	Walking									*Jogging*										*Running*									**FS**
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P7	7	89	1	1	0	0	1	0	1	3	81	0	0	0	0	0	0	0	1	3	0	0	0	0	0	1	0	5.5348
P8	4	3	0	0	0	0	1	0	0	1	2	0	1	1	1	0	1	0	8	96	0	0	0	0	0	0	0	7.1609
P9	9	110	1	0	1	0	0	0	1	3	16	1	0	0	1	0	0	1	9	4	0	1	0	0	0	0	1	5.1645
P10	9	25	1	0	0	1	0	0	1	3	27	1	0	1	1	1	1	0	1	9	0	0	0	0	1	1	0	5.142
P11	5	87	1	0	0	0	1	1	0	4	1	0	0	1	0	0	1	0	3	11	0	0	0	0	0	0	1	5.6732
P12	6	2	0	1	1	0	1	0	0	5	19	1	0	1	0	0	1	0	2	2	0	0	1	0	1	1	1	5.1238

Figure 4.5: Initial Exercise Program for all Patients

Table 4.3.1 gives an overview of the average stats for these EPs. For both men and women, this table displays the average amount of each exercise type given, with the average intensities and duration of those exercises.

	Exercise Type	**Average Amount of each exercise**	**Average exercise intensity**	**Average exercise duration**
Men	Walking	5	5,50	63,50
	Jogging	5	5,67	24,17
	Running	2	4,83	18,00
Women	Walking	3	6,67	52,67
	Jogging	3	3,17	24,33
	Running	2	4,00	20,83

Table 4.5: Table of average stats from exercise programs given to men with the simple human model

As this test was based on the simple human model, the EPs could include all three types of exercise(Walking, Jogging and Running) no matter the health situation and capabilities of the patient. Taking a look at the EPs created for the patients it is clear that the Genetic Algorithm has found many different ways of creating EPs that meet its definition of being good, that is, having a high enough fitness score. All types of exercise are present, with intensities varying from 2-9 for walking, 1-10 for jogging and 1-9 for running. This suggests that a wide range of intensities could improve the patients conditions for exercising. The duration of the exercises ranged from 8-124 minutes for walking, 1-81 minutes from jogging and 1-96 minutes for running. This indicates that a wide variety of exercise durations could improve the patients conditions. Table 4.3.1 shows that the average amounts of walking and jogging exercises were higher than running exercises for both genders, indicating that walking and jogging has better effects on health parameters. The men walked an jogged at an intensity around 5,6 and slightly lower for running at 4,83. For the women the intensities were much more varied with walking coming in at an average of 6,67, jogging at 3,17 and running at 4,00, this could mean that for men there is a set intensity of around 4-6 that works best no matter the exercise, while for women the best intensities varies for each exercise. For both genders, the duration of the jogs were longer than the runs and even longer for walks, suggesting that the patients are able to do easier exercises for longer periods than harder ones. Also suggesting that the implementation is working as intended.

Figure 4.6 shows the average changes in the metabolic health parameters of the patients after eight weeks of exercise for the men, and figure 4.7 displays the same for women.

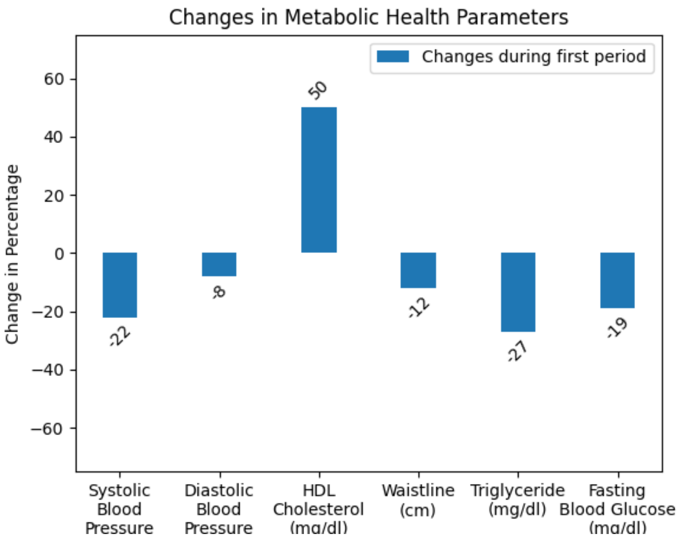

Figure 4.6: Changes in metabolic health parameters for men

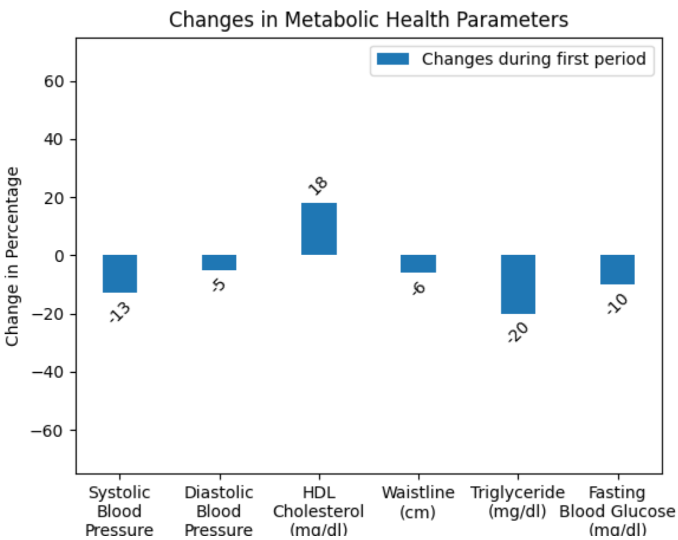

Figure 4.7: Changes in metabolic health parameters for women

After the eight weeks of exercise were complete, the patients were checked to see if they still had MS. Table 4.3.1 shows which patients still had MS and which ones that were no longer defined as having MS. As seen in chapter 2.1, the patients are defined as having MS if three out of five clinical health risks are out of ordinary ranges.

Men						
Patient	P1	P2	P3	P4	P5	P6
Initial Risk Factors	5	5	5	5	5	5
Risk Factors after 8 weeks	2	2	0	2	2	3
MS Check	No	No	No	No	No	Yes
Women						
Patient	P7	P8	P9	P10	P11	P12
Initial Risk Factors	5	5	4	5	4	5
Risk Factors after 8 weeks	2	5	4	3	0	2
MS Check	No	Yes	Yes	Yes	No	No

Table 4.6: Metabolic syndrome status check after 8 weeks

Looking at the changes in health parameters in figure 4.6 and figure 4.7, it is clear that the exercise period has given huge improvements in the patients metabolic health parameters. The men reduces their blood pressure, waistline, triglycerides and fasting blood glucose more than the women on average. They also had better improvements in their HDL Cholesterol levels.

As for whether the patients were able to rid themselves of MS, we again take a look at table 4.3.1. Every man in the data set initially had 5/5 clinical risk factors, three women also had 5/5 and two women had 4/5. After the eight week program was complete, 4/5 men were no longer defined as having ms while only 3/5 women achieved the same. In combination with the men having bigger changes in their metabolic health parameters, it is clear that the men achieved bigger health benefits in total.

Experimental Test 2: Secondary Exercise Period

The second experimental test subjects the patients to a second eight-week period of exercise building on the results of the first period. After the exercise period was complete, the resulting changes in health parameters were recorded. The EP created by the simulator for each patient can be seen in figure 4.8. An explanation of how to read these tables was given 3.3.

Simple Human Model: Secondary Programs Men																												
	Walking									*Jogging*									*Running*									FS
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P1	1	82	0	0	0	1	1	1	0	7	10	0	0	1	0	1	0	1	7	39	0	0	0	0	0	0	0	4.1684
P2	1	57	0	0	1	0	1	1	1	2	55	0	1	0	1	1	1	0	7	9	1	1	0	1	0	1	0	2.4374
P3	1	2	1	1	1	1	1	0	0	4	27	1	0	1	0	0	1	0	6	3	0	1	0	1	1	0	0	3.2438
P4	8	118	0	0	1	0	0	1	1	1	47	1	1	1	1	0	1	0	6	50	0	0	0	0	1	0	0	2.3894
P5	1	17	0	0	1	0	1	0	0	2	35	1	1	1	0	0	1	0	9	0	1	1	0	1	0	1	0	4.881
P6	1	7	0	1	1	1	0	0	0	7	32	0	1	1	1	1	1	1	2	6	0	0	1	1	0	0	1	4.0946

Simple Human Model: Secondary Programs Women																												
	Walking									*Jogging*									*Running*									FS
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P7	3	35	0	0	0	0	0	1	1	4	1	0	1	1	0	1	1	0	8	5	0	0	0	1	0	1	1	2.1621
P8	4	101	0	0	0	1	1	1	0	3	28	1	0	0	1	0	0	0	3	10	0	0	0	1	1	0	1	4.5855
P9	2	7	0	1	0	0	0	0	0	4	22	1	1	0	0	1	1	1	3	13	0	0	0	1	0	0	1	4.6002
P10	2	12	1	0	1	1	0	1	1	5	65	1	0	0	0	1	1	0	6	101	0	0	0	0	0	0	0	4.5319
P11	1	38	1	0	0	1	0	0	1	1	70	0	1	1	0	1	1	0	7	64	0	0	0	0	0	0	0	2.7857
P12	1	116	1	0	1	0	1	1	0	4	47	0	1	0	0	0	0	1	8	7	1	1	0	1	1	0	1	2.1551

Figure 4.8: Secondary Exercise Program for all Patients

Table 4.3.1 given an overview of the average stats for these EPs. For both men and women, this table displays the average amount of each exercise type given, with the average intensities and duration of those exercises.

	Exercise Type	**Average Amount of each exercise**	**Average exercise intensity**	**Average exercise duration**
Men	Walking	3	2,17	47,17
	Jogging	4	3,83	34,33
	Running	3	6,17	17,83
Women	Walking	3	2,17	51,50
	Jogging	3	3,50	38,83
	Running	2	5,83	33,33

Table 4.7: Table of average stats from exercise programs given to men with the simple human model

Building upon the updated health parameters of the patients after the first eight-week period, the second period put the patients through another eight weeks of exercise. Unlike the first batch of exercise programs given, the second period gave the patients more similar EPs. Looking at the men's programs, all but one of the patients were given a walking intensity of 1, suggesting that the easy walks is a good way to exercise, though the duration of those walks varied from 2 to 118 minutes, which is hard to find reason in. The men's jogging and running exercises varied from intensity 2-7 for jogging for a duration of 10-32 minutes, while the running was much lower numbers below 10 minutes, with two outliers at 39 and 50 minutes, with varying intensities for all men. The women were in general given exercises with low intensities varying from 1-5 for walking and jogging and slightly higher for running. The durations of the exercises ranged from 7-116 minutes for walking. The average amounts of each exercise were close with each patient doing an average of between 2-4 of each exercise, though in real life doing 4 instead of 2 exercises is a big difference. Interestingly, the average intensities of running were the highest out of all the exercises for both genders, suggesting that running gives better results for a patients health.

Figure 4.9 shows the average changes in the metabolic health parameters of the patients after eight weeks of exercise for the men, and figure 4.10 displays the same for women.

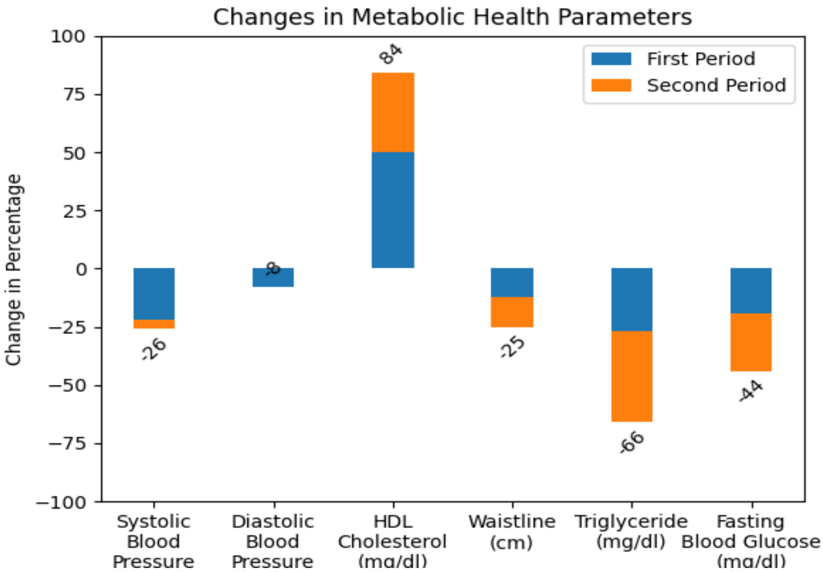

Figure 4.9: Changes in metabolic health parameters for men

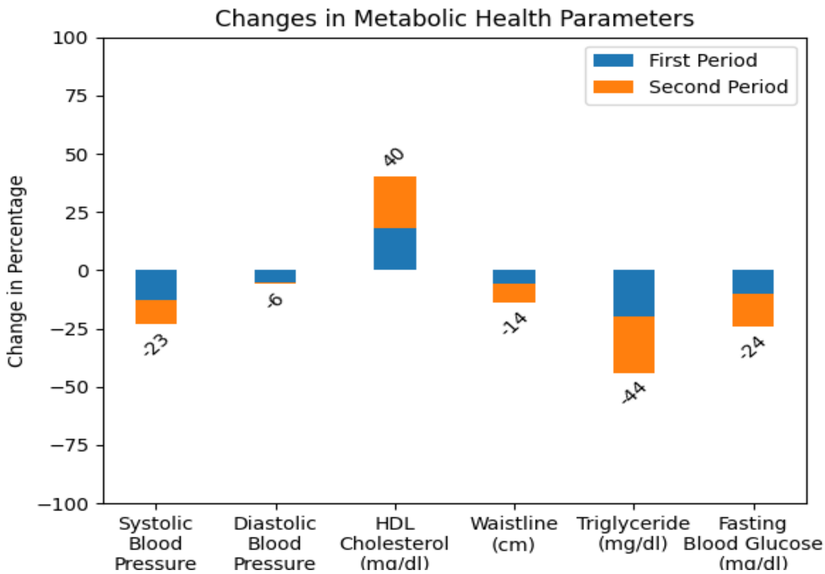

Figure 4.10: Changes in metabolic health parameters for women

After the eight weeks of exercise were complete, the patients were checked to see if they still had MS. Table 4.3.1 shows which men still had MS and which ones that were no longer defined as having MS. As seen in chapter 2.1, the patients are defined as having MS if three out of five clinical health risks are out of ordinary ranges.

Men						
Patient	P1	P2	P3	P4	P5	P6
Initial Risk Factors	5	5	5	5	5	5
Risk Factors after 16 weeks	0	0	0	0	0	1
MS Check	No	No	No	No	No	No
Women						
Patient	P7	P8	P9	P10	P11	P12
Initial Risk Factors	5	5	4	5	4	5
Risk Factors after 16 weeks	2	3	1	1	0	0
MS Check	No	Yes	No	No	No	No

Table 4.8: Metabolic syndrome status check after 16 weeks

Taking a look at the updated health parameters in figure 4.9 and figure 4.10, it is clear that the men were no longer improving the most. Though it is important to note that once the patients reach a certain level for a health parameter, it will stay balanced at that point. The men had already reached some of those points, which is why the improvements faded slightly. The women improved more in blood pressure, HDL Cholesterol, while the improvements in waistline, triglycerides and fasting blood glucose were mostly the same.

Looking at table 4.3.1, every man in the dataset had rid themselves of all clinical risk factors, effectively removing themselves completely from the definition of having MS. As for the women, 5/6 of them were now outside the scope of MS by having less than three clinical risk factors left. One woman still had MS with three risk factors still present.

Simple Human Model Results

Looking at the results from subjecting the patients to two eight-week periods of exercise with the SHM, some important results stands out. First, by using the SHM, motivation and which exercises the patients were capable of were not included. This meant that the patients were given exercises that they probably could not perform in real life, it is not probable that an obese woman is able to run at intensity 8 for 96 minutes, which one of the EPs suggested. Further, as motivation was not a factor, all the patients completed every exercise no matter how challenging, this would most likely not be the case in a real life setting. ET1 suggested that walking was the best for improving a patients health, while ET2 contradicted this by suggesting that running is the best exercise for the patients.

While this could be the result of random chance and the patient data set not being large enough, it is not likely. This is because every patient with MS, while different, all aim towards the same goal of losing weight. While, the EPs are meant to be tailored to each individual patient, they should not be this different.

The changes in health parameters from this experimental test is therefore not trustworthy. Out of the 16 patients, only one remained with MS after the 16 weeks, which seems unrealistic given that they were all well within the ranges of having MS. Thus, while the simple model does simulate an exercise period and gives results based on generated EPs specifically made for each patient, the results bear little meaning when the model is not detailed enough to give reasonable results.

4.3.2 Phase 2: Simulating With Advanced Human Model

Phase two of the experimental tests dives in to how the added parameters in the AHM allows the evolution part of the algorithm to explore different solutions that may be more accurate. As in phase one, the patients undergo an initial eight-week program and a second eight-week program. The changes in metabolic health parameters after each exercise period is presented.

Experimental Test 3: Initial Exercise Period

The third experimental test subjects the patients to an eight-week period of exercise. After each exercise period is complete, the resulting changes in health parameters were recorded. The EP created by the simulator for each patient can be seen in figure 4.5. An explanation of how to read these tables was given 3.3.

Advanced Human Model: Initial Programs Men																												
	Walking									*Jogging*									*Running*									FS
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P1	3	86	0	1	1	0	1	0	1	3	34	1	0	0	1	1	0	0	5	1	1	0	0	0	1	0	1	5.3203
P2	2	32	1	1	1	1	1	0	0	7	12	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	6.1697
P3	4	99	0	0	0	1	0	0	1	3	9	0	0	0	0	0	0	1	3	12	0	0	0	0	0	0	0	5.0473
P4	5	67	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.1969
P5	3	76	0	0	0	0	0	0	0	1	27	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.2715
P6	9	55	0	0	1	0	0	1	0	9	10	1	0	0	0	1	0	1	9	10	0	0	0	0	0	0	0	5.318

Advanced Human Model: Initial Programs Women																												
	Walking									*Jogging*									*Running*									FS
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P7	9	23	0	0	0	0	1	1	0	5	37	1	0	1	1	1	0	1	4	0	0	0	1	1	0	0	0	5.0821
P8	1	7	0	1	1	0	1	1	1	9	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	7.1426
P9	9	65	0	1	0	1	0	1	0	4	56	1	0	0	0	0	0	1	2	15	0	0	0	1	0	1	0	5.0032
P10	2	77	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.1985
P11	3	37	0	0	0	1	0	0	0	6	17	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	6.0315
P12	9	15	0	1	1	1	0	1	0	2	33	1	0	1	1	1	1	1	7	16	0	0	0	0	0	1	0	5.3286

Figure 4.11: Initial Exercise Program for all Patients

Table 4.3.2 given an overview of the average stats for these EPs. For both men and women, this table displays the average amount of each exercise type given, with the average intensities and duration of those exercises.

	Exercise Type	Average Amount of each exercise	Average exercise intensity	Average exercise duration
Men	Walking	3	4,33	69,17
	Jogging	2	3,83	15,33
	Running	1	2,83	3,83
Women	Walking	3	5,50	37,33
	Jogging	3	4,33	23,83
	Running	1	2,17	5,17

Table 4.9: Table of average stats from exercise programs given to men with the simple human model

Taking a look at the given EPs for the patients with the added constraints of which exercises the patients are able to do, the EPs no longer suggested exercises that were deemed unrealistic for the patient to execute. This meant that there were very few patients given EPs with running as an exercise. In fact, only one man ran, for a duration of one minute at intensity five, and only three women ran, also with very low intensities and durations. Much more emphasis was laid on walking, with both women and men taking many walks for long periods of time at medium to high intensities. There were also some patients jogging, but for far lower durations, though the intensities varied from low to high. This suggests that the added benefit of having motivation as a factor led the simulator to produce much easier EPs.

Taking a look at the averages in table 4.3.2, it is clear that the patients are walking the most, then jogging and lastly running. The intensities and durations for each type of exercise also appear in the same order, decreasingly. Suggesting that the implementation of the exercise simulator is working as intended, and also showing that easier exercises for longer period of time balanced out with harder exercises for shorter periods of time can both be part of a good EP.

Figure 4.12 shows the average changes in the metabolic health parameters of the patients after eight weeks of exercise for the men, and figure 4.13 displays the same for women.

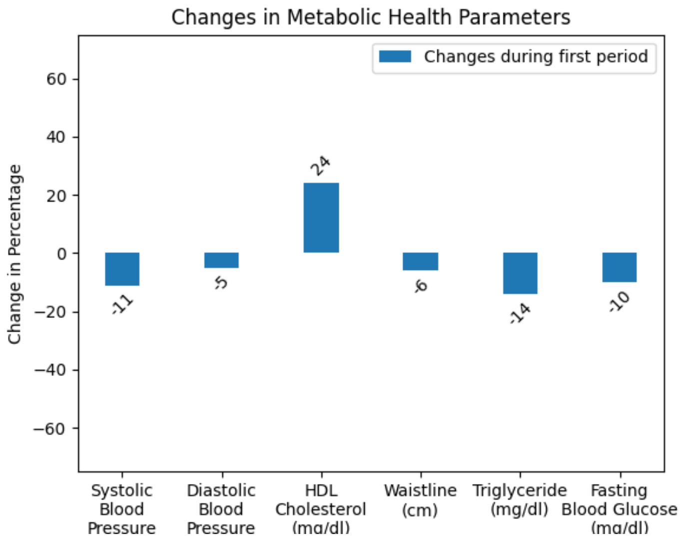

Figure 4.12: Changes in metabolic health parameters for men

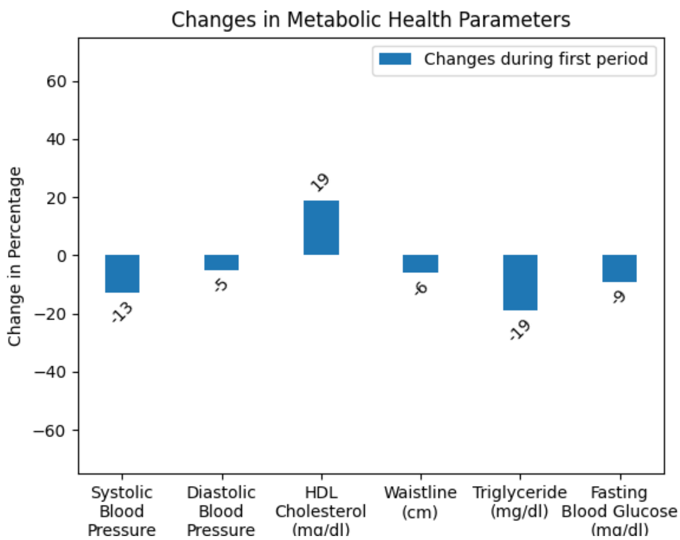

Figure 4.13: Changes in metabolic health parameters for women

After the eight weeks of exercise were complete, the patients were checked to see if they still had MS. Table 4.3.2 shows which men still had MS and which ones that were no longer defined as having MS. As seen in chapter 2.1, the patients are defined as having MS if three out of five clinical health risks are out of ordinary ranges.

Men						
Patient	P1	P2	P3	P4	P5	P6
Initial Risk Factors	5	5	5	5	5	5
Risk Factors after 8 weeks	2	3	2	5	4	1
MS Check	No	Yes	No	Yes	Yes	No
Women						
Patient	P7	P8	P9	P10	P11	P12
Initial Risk Factors	5	5	4	5	4	5
Risk Factors after 8 weeks	2	5	0	5	4	5
MS Check	No	Yes	No	Yes	Yes	Yes

Table 4.10: Metabolic syndrome status check after 8 weeks

As for the health improvements given in table 4.3.2, they were balanced between men and women. The changes in all health parameters were close to equal for both genders, with men improving slightly more in HDL cholesterol levels and women improving more in triglycerides. After the exercise period was complete, three men and two women no longer had MS, which seems a bit unrealistic given that all the patients started with having four or five clinical risk factors.

Experimental Test 4: Secondary Exercise Period

The fourth experimental test subjects the patients to a second eight-week period of exercise building on the results of the first period. After the exercise period was complete, the resulting changes in health parameters were recorded. The EP created by the simulator for each patient can be seen in figure 4.14. An explanation of how to read these tables was given 3.3.

	Advanced Human Model: Secondary Programs Men																											
	Walking									*Jogging*									*Running*									FS
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P1	1	68	1	1	0	0	0	1	0	9	22	1	0	0	0	0	0	1	3	6	0	1	1	1	1	0	1	2.0357
P2	7	9	1	0	0	0	1	0	0	1	41	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	4.7488
P3	6	11	1	0	0	1	1	0	1	3	45	1	0	0	1	1	0	1	4	12	1	0	1	1	1	1	0	2.2848
P4	4	83	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.1935
P5	9	39	0	1	1	0	1	1	1	3	42	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.8365
P6	2	11	0	0	0	1	0	0	1	8	20	0	1	1	1	0	1	1	7	57	0	0	0	0	0	0	0	4.6584

Advanced Human Model: Secondary Programs Women																												
	Walking									*Jogging*									*Running*									FS
	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	I	D	M	T	W	T	F	S	S	
P7	8	73	1	0	0	0	0	0	0	8	32	0	1	1	1	0	0	0	3	11	0	0	0	0	1	1	1	2.1887
P8	3	103	0	1	0	1	1	1	1	2	12	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	5.9322
P9	8	51	1	1	0	1	0	0	0	3	38	1	1	0	1	0	0	0	9	12	0	0	1	0	0	0	1	2.1327
P10	7	95	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.5246
P11	5	59	0	0	1	0	0	0	1	8	2	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	6.1059
P12	7	69	1	0	0	1	1	1	1	7	45	1	0	0	1	0	0	1	4	6	0	0	0	1	1	0	1	3.0452

Figure 4.14: Secondary Exercise Program for all Patients

Table 4.3.2 given an overview of the average stats for these EPs. For both men and women, this table displays the average amount of each exercise type given, with the average intensities and duration of those exercises.

	Exercise Type	**Average Amount of each exercise**	**Average exercise intensity**	**Average exercise duration**
Men	Walking	3	4,83	36,83
	Jogging	3	4,00	28,33
	Running	2	2,33	12,50
Women	Walking	4	6,33	75,00
	Jogging	3	4,67	21,50
	Running	1	2,67	4,83

Table 4.11: Table of average stats from exercise programs given to men with the simple human model

Taking a look at the exercise programs given to the patients in table 4.14, some clear indications stand out. As in the initial exercise period, there is very little running, both because many patients are unable to do it, and because it requires a great deal of motivation. The women typically got EPs with long walks at high intensities with some moderate jogging as well. While the men were more evenly balanced at walking and jogging. Though the intensities and durations of the workouts still vary quite a bit, suggesting that the many kinds of exercise is effective at combating MS. Like in the initial exercise period with the AHM, the patients are given EPs with mostly walking exercises, some jogging and a bit of running. The Intensities and durations of the exercises also appear in this order, suggesting further that a balance between many long walks at high intensities balanced with moderate amounts of medium length jogging at moderate intensities and a few runs at low intensities for a short time is the best way to exercise for patients with MS.

Figure 4.15 shows the average changes in the metabolic health parameters of the patients after eight weeks of exercise for the men, and figure 4.16 displays the same for women.

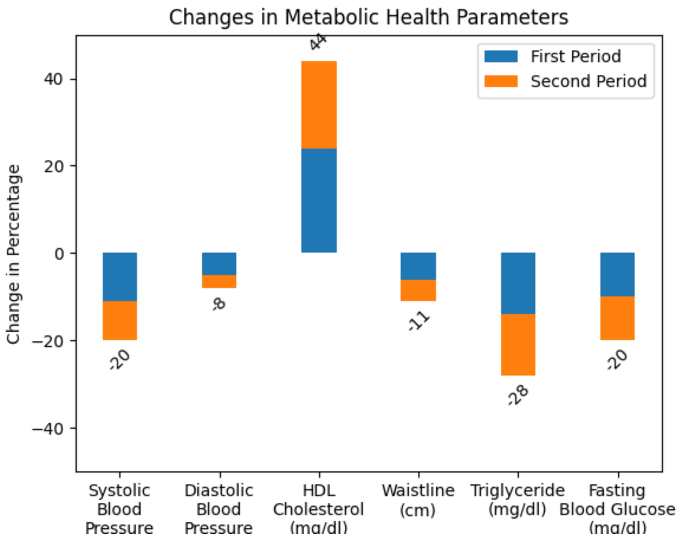

Figure 4.15: Changes in metabolic health parameters for men

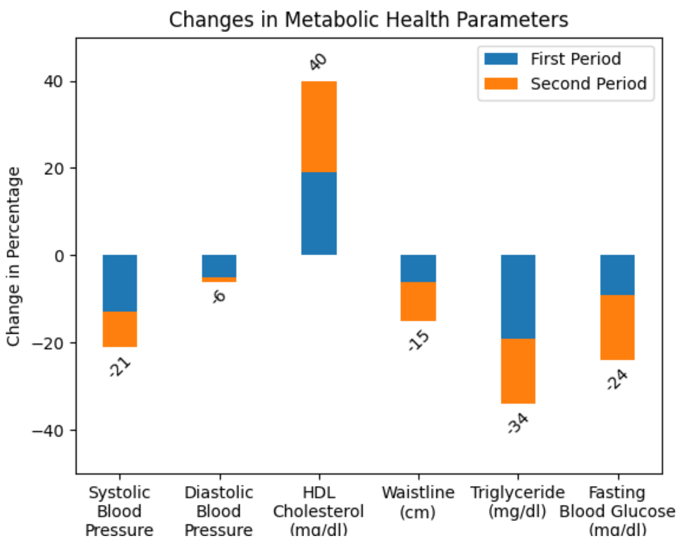

Figure 4.16: Changes in metabolic health parameters for women

After the eight weeks of exercise were complete, the patients were checked to see if they still had MS. Table 4.3.2 shows which men still had MS and which ones that were no longer defined as having MS. As seen in chapter 2.1, the patients are defined as having MS if three out of five clinical health risks are out of ordinary ranges.

Men						
Patient	P1	P2	P3	P4	P5	P6
Initial Risk Factors	5	5	5	5	5	5
Risk Factors after 16 weeks	2	1	1	3	4	1
MS Check	No	No	No	Yes	Yes	No
Women						
Patient	P7	P8	P9	P10	P11	P12
Initial Risk Factors	5	5	4	5	4	5
Risk Factors after 16 weeks	1	3	0	5	3	0
MS Check	No	Yes	No	Yes	Yes	No

Table 4.12: Metabolic syndrome status check after 16 weeks

The health improvements after the second eight-week period in general were balanced between the genders, with women improving slightly more in fasting blood glucose. As can be seen in table 4.3.2, after 16 weeks of exercise, four out of six men now were rid of MS while three out of six women achieved the same. This still seems unlikely in a real life setting. Of course the metabolic health parameters would change, but these changes seems to be too drastic.

Advanced Human Model Results

The results of putting the patients through the 16 weeks of exercise with the AHM were quite different than the results from phase one. Unlike the simple model, the patients now had the added factor of motivation and the exercises they were capable of doing. The EPs given to the patients seemed quite realistic and doable for the patients. A lot of emphasis was put on walking and jogging at low to medium intensities which is what real life patients are also doing as seen in section 2.2.1. The fact that the average amount of walks was higher than jogging and much higher than running, in addition to the average intensities and durations of the exercise types following the same order, for both genders, is highly interesting. It is clear that the AHM has found a blueprint to how the EPs for patients with MS should be. High amounts of high intensity walks for long durations in addition to medium to high amounts of moderate intensity jogs at medium durations and low amounts of low intensity runs for short durations comes toghether to form a balanced, solution EP for the patients.

However, the resulting changes in metabolic values seems a bit drastic. About half the patients were able to rid themselves of MS after 16 weeks. Each health parameter improved drastically which would probably not happen in real life. Thus, the AHM let the simulator create much more realistic EPs, but the changes in health parameters still seemed unrealistic. A way to rectify this would be to change the health parameter equations used to give less benefit for the same amount of exercise.

As the AHM gave stronger results, it is natural to think that an even more advanced model would give even better results. Adding parameters such as average amounts of sleep or calories consumed and burned in day in the human model would make the simulations even more realistic, provided that the simulator used these parameter appropriately.

4.3.3 Evaluation of the Experimental Test Results

Taking a deeper dive into the results of the experimental tests, some main findings was discovered. Firstly the AHM let the simulator create much more realistic EPs for the patients than the human model. The basic human model allowed the GA to create EPs that included exercises the patients were probably not able to execute. While, the unrealistic exercises were reason for concern, the non existent motivation factor made it even more so. Throughout this thesis, the importance of motivation for patients with MS has been thoroughly investigated. When motivation is simply left out of the equation, the patients become almost like robots exercising that have no thoughts, just health parameters and a list of things to do. This is not very much like humans at all. Though the resulting EPs could still, accidentally, be optimal or close to optimal, it is highly unlikely. Also it is much better to include motivation just to be sure that it is taken into account, even if the implementation of motivation as a factor in the simulator is less than optimal, which is hard to know for sure.

The resulting health parameter changes from the AHM were still a bit drastic, though they are probably more realistic than the ones from the SHM. This arises the questions of whether an even more AHM would allow the simulator to simulate more realistic exercises and thus give more accurate EPs and adjustments in health parameters. This is definitely worth looking deeper in to.
Other factors that the choice of human model are also contributing to the results. As seen in 3.5, the simulator calculates the health adjustments based on some health equations that have been created to calculate the impact on the patients health parameters by the exercises. These equations are very generalized and probably too simple to accurately display the changes as they are in real world. This may be the reason why the adjustments in health parameters are too drastic in both human models.

Taking a look at the EPs created by the GA in the simulator, there are several interesting findings. First off, they are definitely more accurate when created using the AHM. Allowing exercises such as running at intensity 10 for 100 minutes for obese people is not realistic in a real world setting, like the SHM did. It is clear that the AHM was superior in this regard. As for the EPs created by the AHM, they still seemed a bit off. Each patient got quite different EPs, which was intended as they should be tailored to each specific patient, however, not as different as the EPs they were given here. Though interestingly, the 'average' as seen in table4.13EP found by averaging out all the exercises, seems to be the most industry-like EP of them all.

	Amount	**Intensity**	**Duration**
Walk	3	5	54
Jog	3	4	26
Run	2	4	15

Table 4.13: Average EP of all patients with both humans models and both exercise periods

This suggests that the middle ground for the EPs is actually very close to what humans are already doing. Though the total workload is a bit much with, this could be because of the energy balancing used in the simulator allows for too many exercises in a week. If the standard deviation of each EPs exercise duration and intensities were not so far from the average, they would be very realistic, specifically tailored EPs for each patient. Though one cannot conclude that the EPs created are here are suboptimal, each individual EP seem to be a bit too far out from the average EP.

All types of exercise were given a duration of 0-103 minutes which seems quite like industry standard EPs given to MS patients as seen in 2.2.2. The GA was in theory allowed to create exercises as long as 1440 minutes(an entire day), but it got nowhere close to that, suggesting that the GA at least to some degree creates realistic EPs for the patients. As seen in section 2.1, the main goal of the exercises is always to lose weight, which can be achieved in many different ways, the important thing is to burn calories, which is done by moving. One could argue that the best EP for a patient with MS is an EP that the patient will actually execute.

Comparing the EPs given with industry standard ones given to MS patients, they seem to be within the boundaries of what can be considered normal. Thus, the simulator and GA is working as intended, though it could use more fine tuning.

Chapter 5

Conclusion and Future Work

This chapter gives a discussion of the model and results in context of the experimental tests, research questions and research goal. Then, the contributions to the field are given, finally the possible ways of continuing this work in the future is presented.

5.1 Discussion

At the beginning of this thesis, a main goal was set. This main goal was to solve the multi objective optimization problem of creating exercise programs for people with MS by utilizing artificial intelligence. The main goal was divided in to three research questions:

Research Question 1: *To what abstraction level must a human be accurately modeled so as to balance accuracy and complexity of the model to produce realistic training programs from a genetic algorithm?*

Research Question 2: *In which ways will the produced exercise programs from an evolutionary algorithm differ from traditionally made exercise programs?*

Research Question 3: *What effect does a simulated exercise period have on the health parameters of a patient with Metabolic Syndrome?*

The main goal of this work has been to solve the multi objective optimization problem of creating EPs for people with MS by utilizing artificial intelligence. To specify the direction of the work, the three research questions were used to guide to process of developing the model and testing it afterwards. Helping patients with MS by creating custom made EPs using the GA was the intention behind the entire process of developing the method used in this work.

The experimental tests done in phase one were intended to create EPs for the patients and measure their resulting health parameter changes after the EP was complete. To this extent, the test was successful. However, as the resulting health parameter changes were unrealistic in the sense that almost every patient was completely rid of MS after only 16 weeks of exercise, the test results can not be trusted. The simple human model used was simply not detailed enough to produce accurate EPs and the resulting health parameter changes are therefore not scientifically significant.

Phase two of the experimental tests however, showed more accurate results. By adding the motivational factor of the patients in to the equation, the amount of exercises actually done were much more realistic. Also, adding the factor of which exercises the patients could do made the EPs given the patients much more alike industry standard EPs. Though the resulting health parameter changes were still a bit drastic, they were much more in alignment with the results of the studies found in 2.3. It is probable that adding even more details in to the advanced human model would lead to even more accurate EPs and therefore more scientifically significant resulting health parameter changes. It is therefore safe to say that the answer to research question one is that a more accurate human model gives closer to optimal results in terms of creating EPs for the patients.

As seen in 2.2.2, the standard EP for a patient with MS usually consists of walking and jogging, with other exercises added if seen appropriate by the patients doctor. Either way, the main goal is almost always to lose weight, so it does not really matter how the patient exercises, as long as its sustainable for long periods of time. This work has seen the creation of dynamically generated EPs for each individual patient. To answer research question two: on average, these EPs do not differ much from industry standard ones. There is a reasonable amount of each exercise relative to each other. Though the total amount is higher than what real life patients are given today, this could be a better way to exercise for patients with MS, after all, the entire point of letting AI create EPs was to find new solutions, not old ones. Al though if the generated EPs were just like industry standard EPs, AI would have helped in confirming their effectiveness.

The tables and graphs from the results of the experimental tests done in section 4.3 gave us the answer to research question three. The simulated exercises had huge impacts on the patients health parameters. Each individual health parameter was changed for the better for all patients. There were also other factors that impacted the results of the experimental tests, mainly the way the exercises are simulated. In this work, the results of each exercise was presented as health parameter changed. There changes were calculated by health parameter change equations as seen in section 3.5. These equations are highly simplified versions of how each health parameter would change in real life. While they were enough to produce somewhat realistic results given the exercises done, more accurate equations would probably lead to more accurate results.

Concerning the main goal of the work, solving the multi objective optimization problem of creating EPs for people with MS by utilizing artificial intelligence has been achieved. The multi objective optimization problem was creating the EPs for the patients, which the GA was able to do. However, by implementing a more advanced human model and a more accurate way to simulate exercises and health parameter changes, the resulting EPs would most likely be closer to optimal in terms of helping patients in ridding themselves of MS.

5.2 Contributions

The field of using artificial intelligence to create EPs has only seen its first few steps in the last few years. Some models based on machine learning do exist, but they require a huge initial data set in order to build their model and create EPs. Through the work conducted in this thesis, a new model as been created. Based on evolution, the model creates EPs with no initial data set other than the patients health parameters which can easily be found. The simulator created is very general in its approach to simulating exercises, and could easily be updated with other kinds of exercise, thus it could be used to create EPs for a number of different health conditions, or for athletes or people in general who want to get healthier, stronger, faster or improve their body in other ways. Allowing artificial intelligence to tailor EPs for people in general could definitely be the future of creating EPs.

5.3 Future Work

At the beginning of this work, a scope was set to focus the effort on creating a working Simulator that could create realistic EPs for patients with MS through AI. As this is an entirely new field, there was not much to build upon, meaning that this work takes the first steps in to a new research field. Based on that, there are many possible ways going forward in researching this field on both a broader level, and take a look at other similar problems building on the same basic idea of AI creating EPs. There are also other ways to continue this work by improving on the same idea.

Real Life Testing

This work does not include any real life testing on actual human beings. While the three test persons in the simulator test are based on actual humans. They are only tested in the simulated exercise period. It would definitely be interesting to actually try out the EP's the algorithm creates on actual people with MS to see the results. This could lead to huge improvements in the implementation which in turn could create better EP's in the future.

Improve Human model

The model of the human body used in this thesis is very restricted. Only a few important health parameters are taken into account which makes the results questionable. The human body is after all, a very complex structure with many different systems that work together. While a simple model like the one used in this work gives realistic results, a complete human model with everything taken into account would make the results more believable. Even if the simple model used covers the most important aspects, we can not know whether some other small factor could impact the results without testing it. Therefore, a better human model would be intersting to look in to.

Improve Fitness Test

The fitness test used in this work is a largely simplified way to simulate human exercise. The humans are assumed to be free of any other disease and condition not otherwise specified. They are assumed to sleep, eat and rest perfectly as to not affect the results of the exercises. In the real world, this is not realistic. Especially for humans struggling with MS, diet can be a big challenge which certainly should be taken in to account. The fitness tests of the simulator also calculates the changes in the metabolic values by an equation that while based on research, will not always be accurate. Different humans require different equations and the equation itself is more of a default option for a general population than a specific one. Working on improving the way the metabolic changes are calculated is therefore a priority should this work be continued at a later time. Another interesting thing that could be added in the fitness test is to allow the patients to gain the ability of jogging or running over time as their conditions improve, as this would be closer to a real life setting.

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Appendix

Week 1

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Week 2

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Week 3

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Week 4

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Week 5

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Week 6

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Week 7

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Week 8

	Mon		Tue		Wed		Thu		Fri		Sat		Sun	
	M	I	M	I	M	I	M	I	M	I	M	I	M	I
Walk	20	5	20	5	20	5	0	0	20	5	0	0	0	0
Run	0	0	50	4	0	0	50	4	0	0	50	4	50	4
Jog	12	6	0	0	12	6	0	0	12	6	12	6	0	0

Table 5.1: A full 8 Week Exercise Period. M = Min, I = Intensity.

	Simple Human Model: Men							
	Time	BP_S	BP_D	HDL	Waist	Trig	BG	MS_C
P 1	Initial Stats	181	91	35	105	292	147	5
	8 weeks	126	79	49	94	219	125	2
	16 weeks	119	79	66	80	127	98	0
P 2	Initial Stats	161	88	39	111	300	106	5
	8 weeks	131	80	47	105	260	94	2
	16 weeks	119	80	68	88	145	60	0
P 3	Initial Stats	141	72	35	102	318	127	5
	8 weeks	120	72	68	76	143	75	0
	16 weeks	120	72	77	68	99	60	0
P 4	Initial Stats	186	93	27	118	353	158	5
	8 weeks	118	80	53	97	212	116	2
	16 weeks	118	80	75	79	98	81	0
P 5	Initial Stats	173	86	35	102	265	115	5
	8 weeks	135	79	44	94	214	100	2
	16 weeks	119	79	59	83	138	77	0
P 6	Initial Stats	136	82	27	102	256	117	5
	8 weeks	120	80	33	98	226	108	3
	16 weeks	120	80	43	89	169	91	1

Figure 5.1: Changes in metabolic health parameters for men using the simple human model

Simple Human Model: Women								
	Time	BP_S	BP_D	HDL	Waist	Trig	BG	MS_C
P7	Initial Stats	142	78	42	102	168	147	5
	8 weeks	120	78	52	94	113	130	2
	16 weeks	120	78	56	91	100	125	2
P8	Initial Stats	171	89	34	115	185	205	5
	8 weeks	169	87	35	115	182	204	5
	16 weeks	132	79	44	107	133	190	3
P9	Initial Stats	169	84	34	88	194	113	4
	8 weeks	162	80	36	87	184	110	4
	16 weeks	120	80	46	78	128	93	1
P10	Initial Stats	173	92	42	120	230	129	5
	8 weeks	124	80	54	110	164	109	3
	16 weeks	119	80	70	98	100	85	1
P11	Initial Stats	135	79	38	96	159	111	4
	8 weeks	119	79	52	85	99	89	0
	16 weeks	119	79	61	78	99	75	0
P12	Initial Stats	151	88	46	95	177	109	5
	8 weeks	130	80	51	91	149	100	2
	16 weeks	120	80	65	80	99	78	0

Figure 5.2: Changes in metabolic health parameters for women using the simple human model

Advanced Human Model: Men								
	Time	BP_S	BP_D	HDL	Waist	Trig	BG	MS_C
P 1	Initial Stats	181	91	35	105	292	147	5
	8 weeks	132	80	47	95	227	128	2
	16 weeks	132	80	47	95	226	127	2
P 2	Initial Stats	161	88	39	111	300	106	5
	8 weeks	143	80	43	107	276	99	3
	16 weeks	119	80	56	97	207	78	1
P 3	Initial Stats	141	72	35	102	318	127	5
	8 weeks	119	72	52	89	230	101	2
	16 weeks	119	72	60	82	187	88	1
P 4	Initial Stats	186	93	27	118	353	158	5
	8 weeks	186	93	27	118	353	158	5
	16 weeks	123	79	43	105	269	133	3
P 5	Initial Stats	173	86	35	102	265	115	5
	8 weeks	170	83	36	101	262	114	4
	16 weeks	165	80	37	100	255	112	4
P 6	Initial Stats	136	82	27	102	256	117	5
	8 weeks	119	80	40	92	186	96	1
	16 weeks	119	80	44	88	164	89	1

Figure 5.3: Changes in metabolic health parameters for men using the advanced human model

Advanced Human Model: Women								
	Time	BP_S	BP_D	HDL	Waist	Trig	BG	MS_C
P7	Initial Stats	142	78	42	102	168	147	5
	8 weeks	120	78	52	94	115	131	2
	16 weeks	120	78	71	79	99	101	1
P8	Initial Stats	171	89	34	115	185	205	5
	8 weeks	147	80	40	110	153	195	5
	16 weeks	125	80	45	106	124	187	3
P9	Initial Stats	169	84	34	88	194	113	4
	8 weeks	119	79	54	72	98	81	0
	16 weeks	119	79	71	60	98	54	0
P10	Initial Stats	173	92	42	120	230	129	5
	8 weeks	147	80	48	115	195	119	5
	16 weeks	144	80	49	114	191	117	5
P11	Initial Stats	135	79	38	96	159	111	4
	8 weeks	135	79	38	96	159	111	4
	16 weeks	120	79	42	93	139	105	3
P12	Initial Stats	151	88	46	95	177	109	5
	8 weeks	149	86	47	95	174	108	5
	16 weeks	119	79	61	83	100	85	0

Figure 5.4: Changes in metabolic health parameters for women using the advanced human model

	Advanced Human Model: Men					
	BP_S	BP_D	HDL	Waist	Trig	BG
Init	-11	-5	24	-6	-14	-10
2nd	-9	-3	20	-5	-14	-10
	Advanced Human Model: Women					
	BP_S	BP_D	HDL	Waist	Trig	BG
Init	-13	-5	19	-6	-19	-9
2nd	-8	-1	21	-9	-15	-15
	Simple Human Model: Men					
	BP_S	BP_D	HDL	Waist	Trig	BG
Init	-22	-8	50	-12	-27	-19
2nd	-4	0	34	-13	-39	-25
	Simple Human Model: Women					
	BP_S	BP_D	HDL	Waist	Trig	BG
Init	-13	-5	18	-6	-20	-10
2nd	-10	-1	22	-8	-24	-14

Figure 5.5: Changes in metabolic health parameters for all patients, for both periods, with advanced and simple human model

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