Have you done your squats today?

Why resistance training should be a part of our workout routines

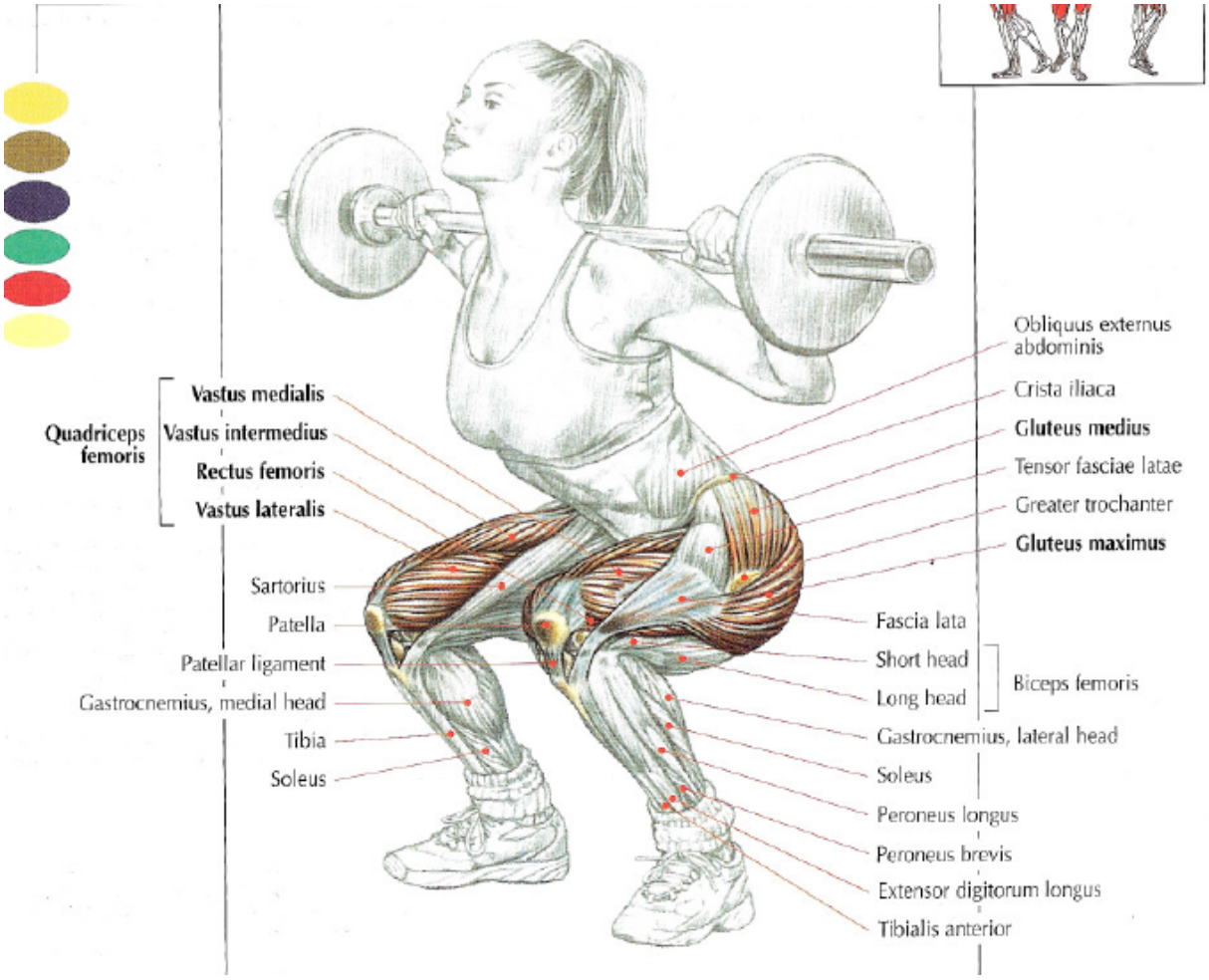

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Table of contents :

Preface

I chose to write my thesis this year about resistance training, as I am convinced that we aren't promoting exercise enough, especially resistance training. It is also known that sports and resistance training offer many health benefits, such as chronic disease prevention, but also resistance training might also help to relieve lower back pain, which many people suffer off. We are currently living such a low activity lifestyle, that many people suffer of a bad posture or other muscular imbalances and weaknesses which lead to pain.

I myself also do resistance training besides playing basketball. So, by doing my research, I might be able to apply certain elements to my own workout routine. This could not only help me in my athletic career, but also in my later life by preventing the aforementioned problems.

This thesis is also fitting my future interests, as I would like to study physiotherapy and so by writing this thesis, I'm familiarizing myself with the anatomy and functions of the human body.

In this thesis all examples are going to be applied to a healthy, sedentary person between the age of 25-45, that isn't suffering any chronic disease or isn't obese/underweight. This is allows us to analyse how resistance training would be beneficial for the general population.

Chapter 1: The introduction to resistance training

This chapter is an introduction to explain certain terminologies and principles that are going to be mentioned throughout this thesis.

1.1 What is resistance training?

"Strength training or resistance training involves the performance of physical exercises which are designed to improve strength and endurance. It is often associated with the use of weights. It can also incorporate a variety of training techniques such as calisthenics, isometrics[1], and plyometrics[2]."[3]

[1] An isometric exercise is an exercise in which a muscle contracts statically without any visible changes in the angles of the joint. The plank serves as an example for an isometric exercise.
[2] Plyometrics are exercises in which muscles exert maximum force in short intervals of time, taking advantage of the stretch shortening cycle.
[3] Source: https://en.wikipedia.org/wiki/Strength_training (27.09.21)

1.2 How does resistance training work?

There are many different methods that can be used in resistance training. In this chapter the basics of resistance training are going to be explored. The main goal of resistance training is to put a stress on the muscle in order to reach the state of *hypertrophy*[4], and further on it can help develop general fitness and metabolic health.

There are 3 factors that will drive our muscle into hypertrophy, which we achieve trough training. Those 3 factors are muscle damage, metabolic stress and mechanical tension. Besides that, there are still different factors which have got to be included in your training program in order to get your muscle to grow, such as adequate training volume or frequency.

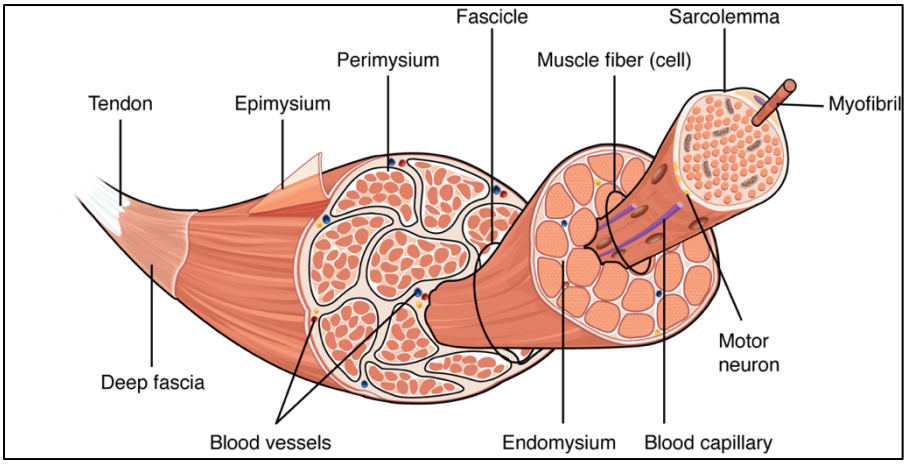


Figure 1: Scheme of skeletal muscle

When talking about the first of 3 factors, muscle damage, researchers often refer to it as exercise induced muscle damage (EIMD). Muscle damage occurs from resistance training, usually during the *concentric and eccentric*[5] contractions.

The biggest amounts of damage in the muscular tissue are observed during the eccentric phase, as the muscle gets lengthened. This is why the descending motion of the repetition need to be executed as well. D.O.M.S (delayed onset muscle soreness). The muscle damage triggers the *mTor*[6] pathway, which regulates the metabolism and activates protein synthesis in order to rebuild and fix the micro tears.

The second factor is metabolic stress. Metabolic stress is a process that is a response to low energy during exercise. Metabolic stress causes the accumulation of certain metabolites (such as lactates or H^+ ions) in muscle cells. During the exercise the muscle is contracting and relaxing, which leads to a pooling effect and a restricted blood flow. With the restricted blood flow, the muscles are hardly getting fuelled by oxygenic blood. The lack of oxygen in the muscles causes the build-up of lactates. The accumulation of metabolites causes anabolic effects like molecular signalling and an increased hormone response, leading to protein synthesis. Metabolic stress is usually achieved by executing higher volume/higher rep sets followed by short rest periods.

[4] Hypertrophy is an increase and growth of muscle cells.
[5] There are two different types of isotonic contractions. The concentric contraction is a type of muscle activation that causes tension on your muscle as it shortens. The eccentric contraction occurs when the muscles lengthens as tension is produced.
[6] The mTor pathway is a functional protein that is in control of protein synthesis.

The third mechanism of hypertrophy is mechanical tension. Mechanical tension is created by moving a heavy weight trough a full range of motion for a period of time. An external load for example a barbell, will place the muscle under tension. This tension is caused by the muscle working against a resistance. Mechanical tension is the force that acts on a material (in this case our muscle fibres) when it gets stretched. In this case, it is the force that acts while stretching out a muscle and serves as a resistance when the muscle tries to shorten by contracting. The longer the muscle is under tension the more mechanical tension is produced. The mechanical tension will promote hypertrophic stimulation by sending signals to our body. This is why correct technique and correct execution of the eccentric[7] are so important for muscle growth, since they induce the most mechanical tension.

All of these three aspects work together. Getting enough mechanical tension on your muscle is the most important aspect for hypertrophy. Whilst getting a good blood flow to your muscles (inducing metabolic stress) or being sore after a workout (D.O.M.S induced by muscle damage) might be nice indicators of a “good” workout, they are not detrimental and do not determine your workout. They are both indirect factors of hypertrophy, whilst mechanical tension is the direct indicator. That being said, it does not mean we cannot have those three factors co-exist, as mechanical tension and eccentrics may lead to muscle damage, for example.

[7] The eccentric contraction is the state, in which a muscle gets stretched during the lowering phase of an exercise.

Chapter 2: The primary prevention

Resistance training has a numerous amount of health benefits, ranging from the primary prevention of metabolic disorders, to preventing physical disorders. In this chapter I will talk about those health benefits, in order to know why we should do resistance training.

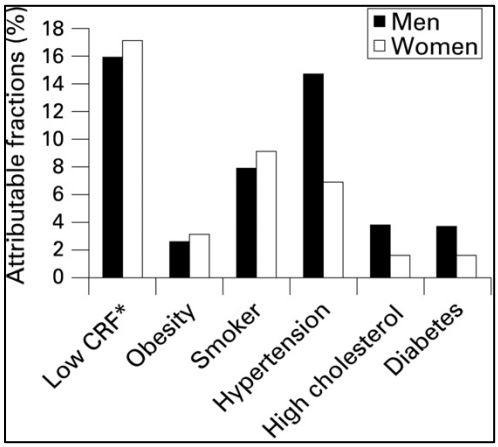
2.1 What are the dangers of physical inactivity?

Physical inactivity is one of the biggest problems we are facing in the 21st century. Inactivity effects our body in multiple ways, such as slowing down our metabolism, losing muscle strength, losing bone density or decreasing our immune systems response. These first problems can all lead up to bigger health hazards like chronic diseases. Inactivity causes the following chronic diseases:

- Obesity
- Coronary heart diseases, elevated risk of heart attacks and other heart diseases
- High blood pressure
- High cholesterol
- Stroke
- Metabolic syndrome
- Type 2 diabetes
- Osteoporosis
- Fall risk
- Certain cancers
- Increased risk of mental disorders such as anxiety or depression

Many of these problems presented are related with one another, the common example would have to be high cholesterol levels and any kind of coronary heart disease.

An article by Steven N. Blair called "Physical activity: the biggest public health problem of the 21st century" shows how much we neglect low cardiorespiratory fitness (which is related to physical inactivity) as a potential health danger. In a first study, daily factors such as smoking or obesity, but also a low cardiorespiratory fitness (CRF), were taken into observation and then analysed. The goal of the study was to find out the relation of health problems and their attributable fraction to all-cause death. 40.842 men (3333 deaths) and 12.943 women (491 deaths) participated in this study.



Risk factors such as hypertension or diabetes were diagnosed trough medical examination, whilst the CRF was tested with a maximal exercise test on a treadmill. As we can observe that a low CRF accounts for 16% of deaths in both women and men. Low CRF is the leading cause of death in this study, higher than other diseases that usually get accounted during examinations and get treated afterwards. This supports how inactivity is not considered dangerous enough for our health.

Figure 2: Comparison Table of all-cause mortality in the first study

In the article a second study is shown, 2316 men with type 2 diabetes were followed for an average time of 15.9 years. During that time 179 death through cardiovascular diseases (CVD) occurred. The body mass index and the daily activity levels were taken into consideration.

The participants were split into 3 groups based on their body mass index, group 1 with a BMI between 18.5 and 25.o, group 2 with a BMI between 25.0 and 30.0 and group 3 with a BMI of over 30.0. Group 1 is considered normal weight, Group 2 is considered overweight and Group 3 is considered obese. After creating 3 groups, every group got divided into subcategories based on their daily activity levels ranging from low, to moderate, to high.

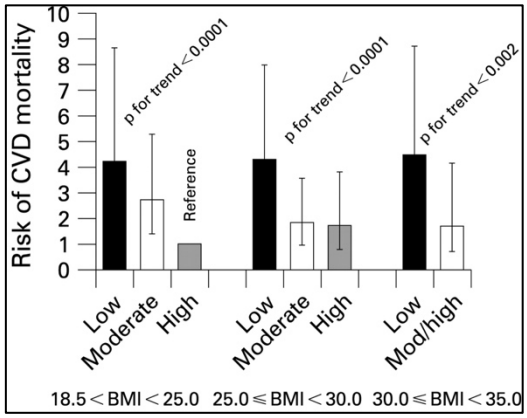


Figure 3: Comparison table of CVD mortality from the second study

We can observe how the risk of CVD mortality climbs in every group from high to low activity. Furthermore, we can see that a highly active obese person has a lower risk of CVD mortality, than a low active normal person. The following establishment underlines how positively or negatively a low/high physical activity level can affect someone's life.

Steven N. Blair himself published the article with the goal to raise awareness towards increasing your physical activity levels, in order to improve the health condition of the general population.

2.2 Why resistance training is beneficial in people with low activity lifestyles

As we know resistance training causes our body to go through adaption progresses at the structural level. If we consider a “standard” job in the 21st century, we can observe how we do spend most of our time in a seated position and that there is little movement involved. This daily inactivity will of course lead to weaker body structures, which is why regular practice of resistance training should be mandatory. In this chapter, we are going to look at the effects of resistance training on certain body structures such as bones or tendons.

The body responds to resistance training with either acute or chronic adaptations. Chronic adaptions are seen as adaptions of the muscular, skeletal, endocrine, cardiovascular and neurological system, whilst acute responses are also observed within the neurological, muscular and endocrine systems.

2.2.1 Increased muscle strength

Increased muscle strength is an adaptation process that is both neurological as well as muscular. Starting off by the neurological adaptations caused by resistance training. When there is force applied to a muscle, signals will be transmitted by the central nervous system which lead to the recruitment of muscle cells. These signals that are transmitted are going to be increased until the muscle becomes tired.

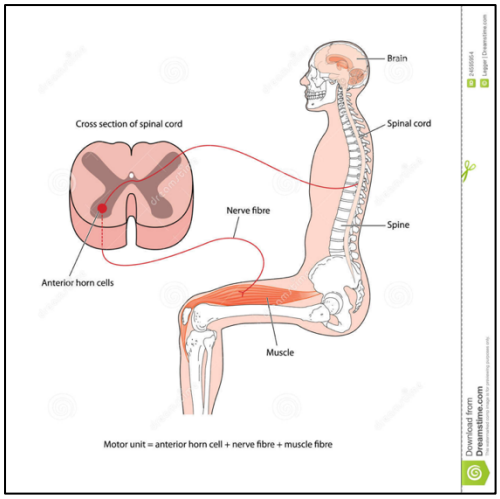


Figure 4: Scheme showing the connection between a motor unit and central nervous system (spinal cord).

There are two neurological factors which influence our muscle strength; motor unit recruitment and rate coding. Motor unit recruitment describes the process of which different motor units (muscle cells in this case) are activated to produce a given level and a certain type of muscle contraction. Rate coding is measuring the frequency at which motor units discharge action potential. Rate coding simply states that as the intensity of the stimulus on the muscle increases, the frequency of action potentials increases as well. To simplify, action potentials in the muscle cause contraction , so increasing those will also lead to increased muscle contraction and greater peak force development.

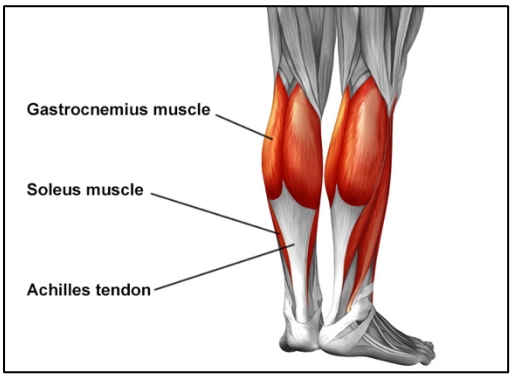
With increased tiredness and repetitions of a given movement pattern, the rate coding become less precise, which leads to worse muscle activity. As chronic neurological adaptations happen, the motor unit recruitment becomes more effective and leads to less muscular tiredness from neurological factors. The chronic neurological adaptation is neuroplasticity, which is supported by exercise. Through neuroplasticity networks in the brain develop and allow for a more efficient execution of processes, such as motor unit recruitment. Another chronic adaptation is decreased co-contraction of antagonistic muscles[8], which leads to greater movement efficiency. These neurological adaptations can be easily observed with novice lifters, who tend to increase strength quickly during their first 2-3 months of lifting, until they hit a plateau[9] do to less neurological adaptations.

In terms of muscular adaptions resistance training leads to hypertrophy, as we already established in previous chapters. The type II[10] muscle fibres will of course have a greater response to resistance training and their increasement has also a greater impact on muscular strength/power. Strength being the skill of moving big loads of weight and power being the skill of moving weighted loads quickly (Jules/second).

Muscular strength benefits us in many ways. It helps us maintain and increase our body composition to a healthier standard. It will increase factors such as stability, balance and flexibility, which is extremely useful for elderly people as it decreases their fall risk. Besides that, strong muscles will perform any movement that requires power more effectively. So all of those adaptions may help relieve chronic pain that are simply caused by muscular weakness, such as some cases of chronic back pain.

[8] oppositely working muscle groups such as the pectoral and trapezius muscles, or the biceps and triceps muscles
[9] a plateau in lifting means the stocking of strength on a certain movement
[10] fast twitch muscle fibres

2.2.2 Increased ligament and tendon toughness



Ligaments and tendons are both connective tissues, serving a different role in our body's anatomy. The tendon connects a muscle to a bone, whilst the ligament connects a bone to another bone. The tendon serves the role of moving the bone or structure, but the ligament serves the role of stabilising a structure. Common examples for each structure, would be the anterior cruciate **ligament**, which connects the femur and the tibia or the Achilles **tendon,** which connects our calf muscles (gastrocnemius and soleus) to the calcaneus.

Figure 5: Scheme of the Achilles tendon and our calve muscles

Resistance training does help with the prevention of injuries through connective tissue adaptations. Resistance training promotes growth of both size and strength in ligaments/tendons and it also improves the strength of the bone to tendon and bone to ligament junction[11]. This will of course decrease the likeliness of a tendon or ligament detaching itself from its structure. Those claims were proven both in animal and human models.

Tendon stiffness is an adaptation that is caused by resistance training. The stiffness describes the mechanical property of how much force needs to be produced in order to stretch the tendon for a certain distance unit. Increased tendon stiffness increases the force that the attached muscle can rapidly produce. Resistance training also shows to increase and enlarge the structural components of a tendon (collagen) and also the density of the fibrils that build a tendon. Similar adaptations of increased and enlarged collagen molecules also happen to the ligaments.

Tendons and ligament are poorly vascularised, meaning that there is no blood flowing directly to this kind of connective tissue. This is why those structure can’t get their nutriments from blood and have to rely on another source, called synovial fluid.

During the loading of a joint with weight, through mechanical tension synovial fluid is forced into the cartilage surfaces. The cartilage is an elastic tissue, it covers the end of long bones at the joint and nerves and serves as protection. An equality between the osmotic pressure and the pressure that forces fluid out of the loaded structure is created. Long term loading makes fluid flush out of cartilage and deforms them temporarily. Afterwards, water is loaded again into the cartilage, making it return to its original form. This compression and decompression and pumping flow of synovial fluid allows for our connective tissue to get their nutriments and adapt themselves.

[11] in this case: the junction describes the connecting point of the bone and the ligament or tendon

The fact that our ligaments and tendons get nutriments under long term loading explains the importance of full range of motion (ROM) and eccentric training. Not only does controlling the eccentric movement offer great hypertrophy adaptations, but it also aids in tendon strength. This is why it is important to perform exercises with a proper technique, using a full ROM and controlling the eccentric, in order to not skip out on structural reinforcement. The KINGS (Kinder im Nachwuchstleistungssport) articles prescribe eccentric training to strengthen tendons, to kids around the age of 10-20, but these concepts of prehab/rehab could also be used in older individuals in order to prevent or rehabilitate their current injuries.

2.2.3 Increased bone density

Resistance training influences all musculoskeletal structures, so of course bones are also affected by resistance training. Resistance training causes our bones to adapt and strengthen, which is key in preventing not only short-term injuries, but also chronic diseases such as osteoporosis[12]. Whilst our bones are more responsive when they are not fully grown out (so in the interval of before 18-25 years, depending on the individual), it is still possible to get them stronger in the age of around 25-45 years, or even in the elder age of above 50 years.

Bone tissue plays a supporting role for our muscles. All of our bones are in a constant cycle of rebuilding. Chemical signals tell certain cells in our body called osteoblasts to deposit new bone, while other chemical signals tell the osteoclasts to resorb the bone. During exercise our body is put under a stress. This physical stress triggers responses by the osteoblasts, that favour bone deposition. Similar to the connective tissues, mechanical loading plays a role in bone density.

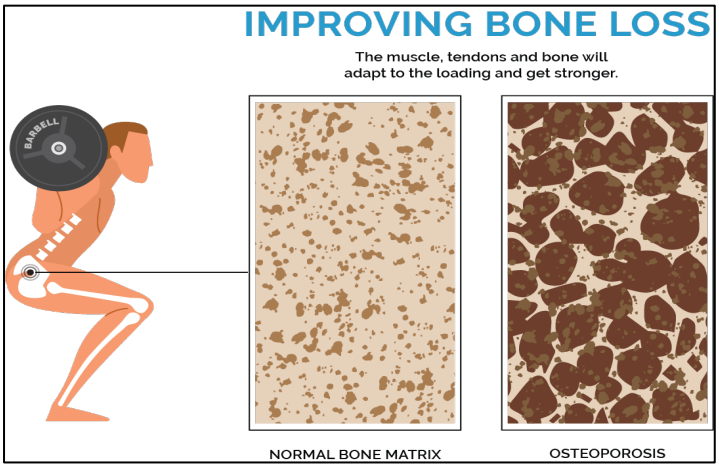


Figure 6: Comparison between a healthy bone and a bone attacked by osteoporosis

Our bone cells called osteocytes can detect the mechanical loading and they also do play a key role in transmitting signals to both our osteoclasts and osteoblasts. The osteoclasts and osteoblasts establish skeletal homeostasis[13]. Mechanical loading simply increases the osteoblastic bone formation and decreases bone resorption by inhibiting the osteoclasts. As an effect, the bone will be formed in local areas of high strain, whilst bone turnover (resorption) and porosity will be decreased, which is a positive adaptation. This also indicates that the effects of mechanical loading are site specific and that the responses are greater in the sites that are under bigger load during the exercise. This can be confirmed as many studies observed great skeletal adaptations in the lower limbs, that are frequently loaded during resistance training.

[12] Osteoporosis is a disease that causes our bones to become weaker and make them much more likely to get injured, since their porosity is increasing.
[13] Skeletal homeostasis is the state in which the 3 main bone cells (osteocytes, osteoblasts and osteoclasts) are in an dynamic equilibrium.

Similar to muscles, in order to increase bone density and positively affect our bones, they needed to be exposed to frequent loading. The loads also need to increase in order to keep up and create stimuli.

One final question is, whether high intensity free weight training (around 70% of a 1 repetition maximum, for 3 sets of 8 repetitions) or moderate intensity machine training (around 40-60% of 1 RM, 3x10-13) is better. An article about "Resistance Training and Bone Mass" by Heidi M. Weingart and co., used both of these models on elderly people (women average of 52 years men average of 54 years) for multiple weeks. It was found that both training styles were causing an increase of bone density. Both training styles were also safe, as long as they were supervised. Both training styles also increased the lean muscle mass, the high intensity training style was more effective at that. The key differences were that the high intensity free weight training resulted in increased strength and peak force. So we can establish that there is no danger in intense free weight training and that machine as well as free weight training helps increase our bone density, which helps us maintain a healthy bone structure.

2.3 How can resistance training prevent or treat chronic diseases?

Now after looking at why inactivity is dangerous, the attention is going to be shifted more towards activity and how it can be beneficial. More specifically we are going to look at how resistance training can be beneficial in its very own manner.

Since there are many details and factors that do go into the structure of a resistance training program, they can't be generally *periodized*[14] (meaning they have to be periodized individually). So, an effective resistance training program should consider moderating factors specific to the practicing individual for desired outcomes. A good program should include *progressive overload*[15], variation and it should periodically change in a systematic manner (so by mesocycles of multiple weeks for example) in order to produce efficient results. But it is also important to be adapted to the individual recovery capabilities of each trainee.

It is proven that resistance training is effective in preventing cardiovascular-, metabolic-, orthopedic diseases, cancer, neuromuscular disorders and aging. This chapter is going to be a generalised overview of the main chronic diseases, more information about disease-specific subcategories can be found in the article *"The Role of Resistance Training in the Prevention and treatment of chronic diseases"* by Joseph T. Ciccolo et al.

Cardiovascular diseases

For any cardiovascular disease (CVD) it is shown that moderate intensity resistance training is helpful. The stress that resistance training puts on your body, causes beneficial biological adaption progresses in your body. In order to have a better understanding of how that specific type of training works in a preventive manner, we need to look at some of the base problems of CVD.

[14] periodizing or Periodization, means the long-term cyclic structure of a workout program in order to achieve a specific result such as maximal strength

[15] Progressive overload means gradually increasing either weight, repetitions or sets in your workout program, order to adapt the body to more stress, for a better response.

Individuals with chronic heart failure (CHF) will experience multiple pathological changes such as fatigue, shortness of breath, reduced ventricular function and most of all reduction of skeletal muscle size and strength. Research found that there is a relation in CHF survival rate and muscle strength. As we know resistance training will either way lead to increased muscle strength, so there might be a possibility that it also helps to improve your CHF survival rate. This has not been proved yet

There is a chance that people with CVD might suffer of hypertension, the medical condition of a high blood pressure. Research found out, that resistance training is beneficial for this group, as resistance training has been shown to lower both systolic and diastolic blood pressure. Though results were found both in sick as well as healthy individuals. People suffering from hypertension or other arterial conditions need to watch out on and that is to avoid valsalva manoeuvres[16] during their lifts, as this particular breathing pattern temporarily increases blood pressure.

Metabolic disease

Resistance training alone is not a stand alone solution to weight loss, as the body needs to be in a caloric deficit in order to lose weight. On the other hand, as resistance training puts our body through adaptation progresses, it can also cause body recomposition. This means, that the percentage of fat tissue lowers, while the muscle tissue simultaneously increases. More fat-free body mass is associated with lower disease risk.

There are specific lipids found in your blood, high-density lipoprotein (HDL), low-density lipoprotein (LDL), non-high-density lipoprotein (non-HDL) and triglycerides. High blood levels of the last three lipids are a good indicator of possible cholesterol and CVD. Once again studies show that resistance training is lowering those 3 blood levels.

Resistance training allows for a better insulin sensitivity and a higher glucose tolerance. Higher insulin sensitivity means that our body cells have a better response to the hormone insulin and a more effective use of glucose for energy. This is especially beneficial for people suffering of diabetes type II, as it can have a reversing effect.

Cancer

Cancer gets treated by chemotherapy, radiotherapy, immunotherapy or surgery, which not only leads to long pauses in exercises, but also causes fatigue, unfavourable changes in body weight/composition and muscle atrophy. Having done resistance training before a cancer diagnosis is a great help, as it might lead to an overall improved well-being during therapy. Resistance training is also used during or post therapy in order to help with side effects. For example, Women that did resistance after their chemotherapy experienced health-related and clinical benefits. Cancer is affected by multiple variables and resistance might not have enough effect on preventing it, but it serves nicely as a way of prehab.

[16] Breathing technique that increases air pressure in the thorax and lungs, by not breathing freely and holding in the breath, in order to help with physical exertion.

Aging

The muscle mass we develop in our youth isn't forever, we need to keep on stimulating our muscles in order to preserve muscle mass, hence why we should do resistance training at any age. That's why people are often talking about "using it or losing it" when it comes to muscles. Even in a higher age, your muscles will still develop, maybe not as quickly though. It is known that resistance training is the most effective intervention in increasing muscle mass in higher ages.

Besides keeping up your muscles, those muscles can still be used. Individuals that practice resistance training, coupled with balance exercises are way less prone to fall risk and damage at a higher age. This very important as it can easily prevent unnecessary injuries at higher ages.

Orthopaedic disease

Orthopaedic diseases are attacking musculoskeletal system, like injured knee ligaments such as a torn meniscus. Resistance training increases the effectiveness of that musculoskeletalsystem and also increases the longevity of the different structures of the musculoskeletal system.

Neuromuscular disorders

Even though there hasn't been done a lot of sufficient research on the correlation of resistance training and neuromuscular disorder prevention and rehabilitation, some evidence was still found. Resistance training with post-stroke patients has shown to improve their gait speed, functional ability and also improvement in quality of life. There is also limited evidence that resistance training might impact positively aspects of pain, well-being, tender points, physical function and depression. Finally, there was still some evidence found for individuals with Parkinsons that it increases muscle mass and strength. Overall, this department still lacks a bit of evidence and some specific research such as neuromuscular adaptions in Parkinsons patients.

Chapter 3: How to use resistance training for our advantage

Having established the benefits of resistance training, it is now important to know how to train efficiently. This chapter is going to talk about training frequency, about exercise and resistance selection (free weight, body weight, machines, resistance bands) and what bad training or overtraining looks like. These are all things that are important to consider if it comes down to creating your own workouts.

3.1 How frequent do we need to do resistance training?

The primary factor of training frequency is the overall fitness level of the trainee. Trainees with lower overall fitness require more rest in between training sessions, while more advanced trainees can tolerate more training volume and more frequent training sessions.

In order to determine adequate training frequency, recovery in between sessions has to be determined first. As already mentioned, this is individual and is based on individual overall fitness. General rule is to leave at least one day of rest in between training the same muscle group(s). Most beginners and novices demand less total volume and frequency in order to have benefits from their resistance training. This is also why most trainees start off with a full body routine, that intents two to three workouts per week. Due to the trainees body not being adapted to the stress of resistance training, they will experience quick benefits due to their body adapting very fast to a new kind of stimulus.

More advanced or intermediate trainees, who's bodies are already accustomed to the stress of resistance training need to adapt their frequency. If they want to continue achieving positive benefits from resistance training, they need to increase their training frequency. They have to train their full body at least three times a week or change to a "split" routine training 4 times a week, in order to accumulate enough work volume to continue progressing. A split[17] routine also allows the trainee to train two days consecutive, avoiding unnecessary fatigue in one or multiple muscle groups.

Very advanced trainees need to train four to six times a week to progress. Another aspect to consider for those trainees is to have them do resistance training twice a day, making them accumulate 8-12 training sessions a week. The advantage of having two shorter training sessions a day instead of one long is reflected in the quality and intensity of the training. These trainees need to use split routine in order to avoid training the same muscle groups on consecutive days, which would lead to heavy fatigue and overall worse training quality.

Novice, intermediate and advanced trainees are labelled after their training experience, in order to class others or ourselves in one of the three categories. This is very simple and based off the years a person is doing resistance training; we are considering someone who does resistance training one year or less a novice, somebody who is already doing resistance training for one or two years is considered an intermediate trainee and lastly somebody who does resistance training for two to three years or longer is an advanced trainee.

[17] A split training routine is a training routine, in which the muscles groups of the body are "split" up into different sessions. For example, an upper body and lower body training routine is also a split training routine.

It is important to have an understanding of why recovery is important for programming our training. In order to understand, we need to consider the physiology of post-exercise recovery, what effects play a role in recovery and how they affect training performance.

Starting off buy the simplest of three sections: muscle damage: EIMD has already been explained in a previous chapter. The damage in the contractile proteins, connective tissue and sarcolemma (muscle cell membrane) by EIMD, leads to disturbances that diminish the muscle's ability to produce peak force until it is repaired. Muscle damage also hinders the ability to transport blood glucose into muscle cells, which causes consequently a decrease in replenishing glycogen storages, which are used by muscles.

The next section are the muscle substrates. Anaerobic[18] exercise will tax the phosphagen energy system, which will then lead to the depletion of the primary substrate (fuel) of the specific energy pathway. In the skeletal muscle phosphocreatine (CrP) is being stored and used during anaerobic exercise in order to continuously provide ATP. The CrP is going to transfer a high energy phosphate to ADP, which allows for ATP resynthesis. This allows to keep on performing efficiently. During high-intensity anaerobic efforts the CrP stores are depleted quickly inside 10 seconds. If we want to continue with high-intensity resistance training, CrP recovery becomes a critical aspect. CrP stores replenish during recovery periods of 30-60 seconds.

The final section to consider, are metabolic by-products that might affect performance during resistance training. During high-intensity exercise ATP turnover rates are increased, which trough complex processes (ATP hydrolysis and increased glycolytic flux) accumulate lactates and protons in the muscle cells. Both lactates and protons can negatively influence and impair continued ATP resynthesis and skeletal muscle contraction. Lactates can hinder the electric stimuli (action potentials) which cause our muscles to contract. Protons lead to a decrease in muscle pH. In the acid state (cellular acidosis) CrP store recovery is impaired. The recovery from cellular acidosis is needed for our body to restore the capacity of CrP regeneration from the phosphagen system.

All of the energy systems in our body are impacted by resistance training, which is why they need to properly recover in between training sessions, so maximal effort and performance can be guaranteed. As we can see, the CrP energy system recovers in a much shorter time, and it is important to consider in between sets. We need to consider retraining a muscle in 24-48 hours to avoid EIMD to interfere with our training performance.

[18] Anaerobic activities are activities in which glucose is broken down without the use of oxygen. Generally speaking, anaerobic activities are mostly fast and explosive movements

3.2 What kind of resistance should be used?

After explaining how frequently we should train and why we should not neglect recovery, we can now advance to the design of our training session. Before looking at exercise selection, in which we determine what kind of resistance (free weight, machine, bands and others) to use, we need to determine the basic structure of our workout. This is called “programming”. There are some basic structures we should always respect in our workouts. These workout structures allow us to perform more efficiently, leading to more ideal responses from our body, and they ensure that we are less likely to injure ourselves.

- Firstly, specific muscle groups (that might be underdeveloped or require more work) should always be prioritized in our workouts. In a hypertrophy-style training (more like “bodybuilding”), but also in a general training style this is useful, since at the beginning of our session we have the least fatigue making us able to connect and develop the target muscle. This could be for example exercises for the lower back or exercises for shoulder health.
- Secondly, larger muscle groups (like the pectorals) should be trained before smaller muscle groups (like the triceps). This is to ensure that we are not entering the main exercises with unnecessary fatigue, which could lead to injury or decreased performance.
- Thirdly, multi joint exercises should be performed before single joint exercises. The reasoning is similar to the second point made. Pulling movements (vertical/horizontal), pressing movements (vertical/horizontal), squatting and hip hinging are the 6 main movements that are performed in multi joint exercises. Something like the extension or raise of a single joint is considered a single joint exercise.
- Fourthly, if free weight exercises are used in the workout, they should be performed before machine exercises. Free weight exercises require more work from the CNS and performing them in a prefatigued state could increase likeliness of an injury occurring. Machine training puts in safer more stable positions, which is why they are less demanding on the CNS. We can perform them easily in a pre-fatigued state after free weight training and we do not have to worry about increased likeliness of injuries.
- Fifthly, when we are performing multiple exercises in one session for one muscle group, we should assure to use multiple “angles” and movement patterns. This is so we can make sure that we trained every part of the muscle group, in every anatomical function. For example, we can train the pectorals in a flat, declined and inclined setting to make sure we target the lower, middle and upper muscle fibres. The same way we change angles, we can also change movements, so we can either push or adduct with our chest muscles.

Now that we know how to arrange different exercise types in our session, their still remains the question of what resistance we should use. This is very hard to generalize, since it is a very individual part of programming. We can still look at both the benefits and disadvantages of different kinds of resistances and decide based on those. To simplify this complex question, we are looking at 4 ways to create resistances: resistance bands, bodyweight, machine weight and free weight.

Starting off with resistance bands, they offer a resistance on their own, ranging from light to heavy depending on the elasticity of the band. We can also use bands to assist a movement, like the pull-up or as a supplemental resistance to a movement, this is called accommodating resistance[19](AR). The pros to resistance bands are; easy use, beginner friendly, portability and AR for both beginners and advanced trainees. The biggest con to resistance band is their constant load. The body can quickly adapt to the band tension making it harder to set new stimuli every training session and to use progressive overload. We can hardly train with only bands, but they might be a good accessory for progressing or regressing the load of a movement.

Bodyweight training, also called calisthenics, uses only our body against gravity as a resistance. The pilar movements of this training style are the push-up, the pull-up, dips and air squats. This covers 5 of the 6 main multi joint exercises. The pros are similar to those of the bands, as the basic movements are rather beginner friendly and allow to develop good awareness, stability of our body and proper technique progressing to weighted exercises. The main con is that progressive overload may be harder to apply and that advanced variations require very specific skills.

Figure 7: The pull-up, one of the basic calisthenic "skills".

Calisthenics are a great way of training, but the more advanced movements require a lot of work, which is why I rather see the basic calisthenics movement being implemented in a training program, in order to raise body awareness and stability.

Training on weighted machines is an accessible training method, if a gym is provided. The machines use weight as a resistance and are guiding us through the full range of motion that the machine offers. This does not require as much stabilization by the body and allow a good focus on the target muscle group and progressive overload can easily be applied. The downside is that being guided throughout the movement does not allow for much freedom. Since everybody's body has different proportions, machines are not a "one fits all" solution. This could lead to discomfort in joint areas. The article "Resistance training and bone mass" showed many positive responses to machine training making it legit to base a good portion of our training on machines.

Free weight is another method mainly accessible if there is a gym. In opposition to machine weights, free weights allow for a lot of freedom throughout the range of motion and require more stabilization. We can also easily apply progressive overloads with dumbbells and barbells, but more freedom also makes more room for mistakes. Technique needs to be supervised to avoid injury, if we are moving heavy free weights or doing high repetition sets. The body shows the most responses to higher intensity free weight training, which is why I think they should be a priority in most programs in order to ensure that we get optimal performance and stay injury free.

[19] Accommodating resistance is used to make a movement equally hard difficult throughout the full ROM. It can be used for example to ease the concentric in a pull-up for beginners, but also used to ensure a harder lockout at the top of the squatting movement.

I personally would start my training off, no matter of the experience level, with a free weight multi joint targeting the prioritized muscle group of the workout, then move on to either some lower intensity bodyweight movements (with or without AR) or free weight movements and finish off the workout with exercises on machines.

The reason the squat was chosen for the title of this thesis is that it represents every single one of the resistance types. It is a multi-joint exercise that can be performed in numerous ways. It is mostly known for its bodyweight version called the “air squat” and the barbell version, known as the “back squat” or even as the “front squat”. We could also execute a squat on machines such as the “hack squat” or the “V-squat". Finally, we can also change the resistance pattern by adding accommodating resistance, either helping us out the “hole” of a squat or opposite, making it harder as we squat up.

Figure 8: The hack squat, a machine version of the squat pattern

3.3 The dangers of a “bad” workout program

There are multiple problems to “bad” workout programs. Some are very direct, while others are rather chronic. The first more direct problem of a “bad” workout program is bad exercise selection. Everybody has different structures so not every exercise is comfortable to every person. A good program offers an exercise selection catered towards the trainee. The exercises chosen are meant to be executed comfortably with a good focus on the target muscles. In a bad program, the exercises chosen might not be comfortable for the trainee and does not allow for the necessary focus on the target muscles. This “uncomfortable” feeling might come from exercise execution compromising joint health, either in the active phase or during the phase in which he sets up, which could lead to injuries short or long term. This problem is easily solved by looking at exercise selection as something rather individual and avoiding “one fits all” mindset.

A second rather direct problem observed in badly structured programs, is frequency. As already explored in a previous chapter, there are justifications to why we should train at a frequency adapted to our fitness level. We need proper recovery for our energy systems in order to perform during our workouts. This suboptimal training frequency can also lead to the opposite, if the trainee is undertraining. Undertraining will not cause the necessary stimuli to the body and will not allow him to progress properly. This will cause plateaus. Besides plateaus, training to frequently may lead to overuse injuries such as tendonitis (and stress fractures, but this is rarely observed with resistance training). These kinds of injuries are induced by a repetitive trauma.

For the target audience there are a few simple tips, that help with their start into resistance training. Firstly, going to the gym with a friend or trainer who has experience in exercise execution can help you build confidence and avoiding injury by establishing a solid exercise execution. Secondly, every trainee can always take advantage of video tutorials of exercise execution and also video recordings of their own execution in order to improve. Thirdly, to avoid overtraining or undertraining, every trainee should have a workout program, that is structured to their own abilities. This program can be supervised by a professional such as a person training coach or physiotherapist (in case of a rehabilitation/preventive program)

There is a solution to overtraining or undertraining, the workout program (as mentioned before). This solution will not only avoid overuse injuries, but also avoid plateaus if executed properly. The solution is training in a cyclic manner. To understand cyclic training, we need to look at the different phases. A cyclic workout program consists of a macrocycle (1-4 years) divided into mesocycles (1-2 months) that consist of microcycles (1 week of training). These are the 3 cycles of periodization[20]. To avoid overtraining, the mesocycle is the most relevant. Periodization is based on the principle of adaptation and overload. We start the mesocycle by a low stress "intro" week. As we advance, we go through multiple "accumulation" weeks. Near the end of the mesocycle we reach a week off overloading the body called the "overreaching" week. We simply finish the mesocycle by a "deload" week, which is low stress, so the body can adequately recover. This process gets repeated multiple times throughout the macrocycle.

With periodized training, the athlete will gradually adapt and build fitness, which avoids the plateaus. Overuse injuries are avoided, since the athletes weekly training stress progressively adapts and is always followed by one week of less volume to allow for recovery.

[20] Periodization is an exercise design technique often used in resistance training in order to cause long term improvements.

3.4 A beginner workout program

Full Body A			
Exercise	Sets & Reps	RiR	Execution
Goblet Squat	2 30sec	/	Kettlebell/Plate
Back extension	2 10-12	2-3	Bodyweight/Loaded
Wall sit	2 30sec	/	Bodyweight/Loaded
Squat	3 6-8	1-2	Barbell/Machine
Romanian Deadlift	3 6-8	1-2	Barbell
Push-Up	2 10-12	0-1	Bodyweight/Loaded
Supported Row	2 10-12	0-1	Machine

Figure 9: Training Day A

Full Body B			
Exercise	Sets & Reps	RiR	Execution
Shoulder dislocation	2 10-12	/	Banded
External rotation	2 10-12	2-3	Dumbbell
Push-Up Isometric	2 30sec	/	Bodyweight/Loaded
Seated OHP	3 6-8	1-2	Barbell/Dumbbell
Pull-Ups	3 6-8	1-2	Bodyweight/Loaded/Assisted
Leg extension	2 10-12	0-1	Machine
Leg curl	2 10-12	0-1	Machine

Figure 10: Training Day B

After talking about the variables that need to be considered in a training program, I had decided that I wanted to include a training program into my thesis. The target audience for my workout program is the healthy sedentary person I talked about in the introduction. I will be breaking down the different ideas I applied to this training program.

Training frequency:

As we see the training program consists of a Full Body Day A and B. The Full Body training split is very beginner friendly as already mentioned. Full body training allows for a high frequency without major recovery problems. Ideally, the trainee should train 3 times a week with this split. He can train by doing workouts A-B-A and then B-A-B in the following week. If, however the trainee does not manage to train three times a week, he can simply do both workouts once a week. If the trainee wants to train more than three times, he can simply up the training frequency by one extra session a week, making it a four days a week training routine.

Volume & Intensity:

Since the program targets beginners, the volume will be rather low to allow their bodies to adapt nicely to the new stimulus. Each repetition-based exercise has a given intensity scheme expressed in RiR (reps in reserve). It prescribes how hard the trainee needs to execute the following exercise by telling the trainee how many repetitions he should “leave in the tank” and not execute. For example, a trainee might be able to do 50kg on the bench press for 10 repetitions pushing his muscles all the way to failure and neglecting technique. This will cause issues on recovery and increases risk of injury, which impacts training performance on the next 2 sessions. If he would train with the prescribed RiR and leave 1-2 (since it is an approximate guess) repetitions, his risk of injury and his recovery would not be impacted as negatively. “Prehab" and “Compound” exercises do not get pushed all the way to failure, as technical breakdown and possible injuries through that could occur. "Accessory” exercises that are bodyweight or machine weight exercises however do get near or failure.

Exercise selection:

Training day A is focused on lower body strength & health. Training day B is focused on shoulder girdle strength & health. I chose to focus those areas, as they are common areas where pain is inflicted.

Each training day starts off with one “mobility” exercise, aiming to strengthen the body through a full range of motion and improve ROM. This exercise should conclude the warmup. After that two “Prehab” exercises will be performed. These aim to strengthen the musculature (through isotonic exercise) and tendons (through isometric exercise) in specific areas. The main part of the training is taken up by two “compound” or multi-joint exercises. The main exercises are done in an agonist-antagonist manner, to avoid fatigue from one main exercise to another. The training is finished off by two “accessory” exercises that target the half of the body that has not been worked out yet previously.

Progression scheme:

Progressive overload needs to be applied throughout the whole time of running the workout program. As sets, reps and intensity are non-changeable variables, weight needs to be increased in order to progressively increase stress on our body. In order to properly apply progressive overload, the trainee needs to do the following: once he hits all the target reps for all the target sets, he should increase weight in small increments (usually 2,5 kg). This principle is the most basic version of periodization and allows for the trainee to learn about the capabilities of his body. As this training plan is meant to be an introduction to resistance training, he should run the program until he hits his very first plateau. After the plateau the trainee can than change to a more individualized training program that would help him break through the plateau.

Conclusion

As a conclusion, I would like to say that resistance training needs to be a necessity in most people's training routines. While not everybody needs to make resistance training their main source of exercise, everybody can benefit from it. Strength training is preventive both in injuries of the musculoskeletal system and in metabolic diseases. This is clearly supported by evidence found in the studies and articles that were mentioned in the thesis.

My claim did also get backed up by the WHO (World health organisation) as they recommended to train every main muscle group twice a week in the prescribed 150 minutes of weekly moderate exercise (or 75 minutes intense exercise) (*since 25 November 2020*).

Even if the WHO recommends resistance training, most of society does not want to do resistance training for their health. Our medicine might be very advanced to operate or treat injuries on the musculoskeletal system, but many people do not even consider resistance training as a part of the treatment. For example, two amateur athletes that get any kind of tendinitis will be told by a doctor to stop playing their sport for a while and maybe take some pain killing or anti-inflammatory medicine for a while. Only one of them considers scaling their sports activity back to isotonic and isometric exercise and working together with a health professional, in order to still load their tendon in a much lower and safe way, than their sport would. In the end the second athlete who uses resistance training to safely load his tendon will much likely experience less trouble during his recovery and return than the first athlete.

This is part of my motivation to become a physiotherapist myself, to show my future patients how much of a positive effect resistance training can have on the body and to even clear up myths such as: “lifting weights will make you less flexible” or “lifting weights stunts your growth”, by offering a well-structured evidence-based therapy to clients. Resistance might be one of the most underrated lifestyle changes, in terms of physical well-being. As an old saying says: “Movement is medicine.”

Finally, I would like to say thank you to Mrs. Hayen and my family for their support and help throughout my whole thesis.

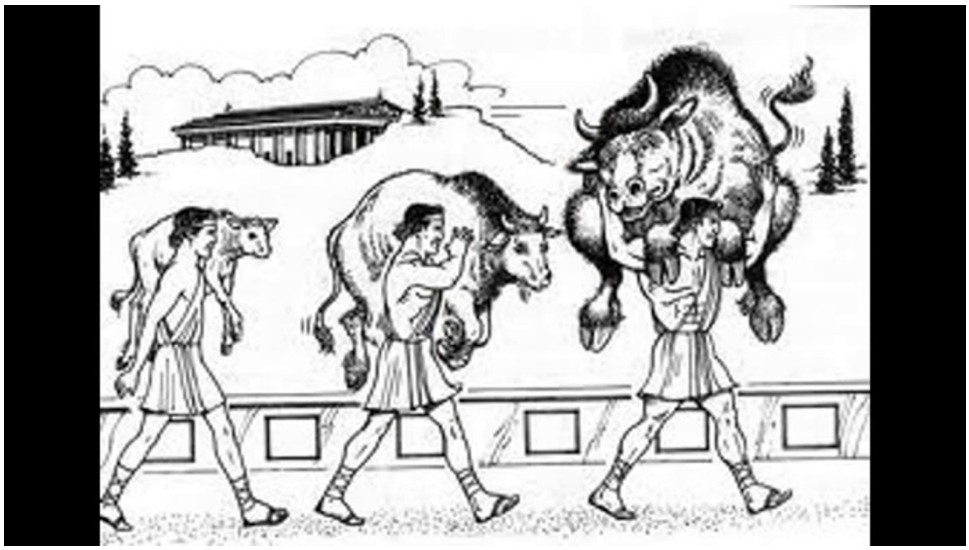


Figure 11: The legend of Milo of Croton, picturing the principle of progressive overload

Sources:

https://ioncardiff.com/the-3-mechanisms-of-hypertrophy/ (20.10.2021)

https://pubmed.ncbi.nlm.nih.gov/28706859/ (20.10.2021)

https://bjsm.bmj.com/content/43/1/1#F1 (21.20.2021)

https://journals.sagepub.com/doi/abs/10.1177/1559827609354034 (14.11.2021)

https://www.britannica.com/topic/resistance-training (12.12.2021)

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4637912/ (27.12.2021)

https://link.springer.com/article/10.2165/00007256-198603010-00006 (27.12.2021)

https://www.unm.edu/~lkravitz/Article%20folder/bonemass.html (29.12.2021)

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6279907/ (29.12.2021)

https://www.nsca.com/education/articles/kinetic-select/determination-of-resistance-training-frequency/ (12.02.2022)

https://acewebcontent.azureedge.net/SAP-Reports/Post-Exercise_Recovery_SAP_Reports.pdf (12.02.2022)

https://www.lonestar.edu/departments/kinesiology/Resistance_Rules-May_2014.pdf (14.02.2022)

Picture sources:

https://www.dreamstime.com/stock-images-nervous-control-muscle-image24595954

https://www.hss.edu/condition-list_achilles-tendon.asp

https://www.p2sportscare.com/resistance-training-for-runners/

https://www.youtube.com/watch?v=nK0gZoI7WxE

https://www.verywellfit.com/top-bodyweight-exercises-for-fitness-and-strength-3498251

https://www.youtube.com/watch?v=rYgNArpwE7E

https://www.healthfitnessrevolution.com/samir-trains-his-strength-like-ancient-greek-athlete-milo-of-croton/

https://www.thestephaneandre.com/how-to-do-squat/