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Muscular activity monitoring to reduce work related musculoskeletal injuries

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY

MASTER'S THESIS 2017

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Cover: different screens of the wristband application

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ABSTRACT

The Swedish society has to carry a significant cost due to sick leave and the initial objective of this project has been to reduce the most contributing cause, which is work-related muscular injuries. By minimising the risk of injury, this would benefit the society, the individual and also the employer. It was found that the work related injuries primarily originated from exhaustion in the skeletal muscles and therefore a monitoring system was developed in order to prevent muscle injury. By notifying the worker when rest is required, in order to minimise the risk of muscle harm due to fatigue, the authors argue the initial objective can be fulfilled.

The project started off with a literature study to fill the biomedical engineering knowledge gap by the authors prior in this project. Work then proceeded by conducting tests on subjects to verify literature theories and discover limitations and opportunities with sEMG technology. Then customer needs and requirements were elicited and combined with expert inputs to produce several concepts which went through an elimination process to end up with one winning concept.

The end result was a product concept which would act as the groundwork for the future development of a real product. The concept consisted of a compression shirt with embedded sEMG electrodes and wires, a sender/receiver unit, a unit to display valuable information for the user, a fatigue analysis method and lastly a technical specification for the future development of a product.

The developed product concept will require an initial, large enough, data collection for the product to “learn” harmful fatigue levels which users should be notified of. Therefore, it will take some time for the product to achieve its initial goal, but the authors argue the product should be produced, considering the large sick leave cost reduction it would achieve.

Keywords: Sick Leave, EMG, Muscle Injury Prediction, Cost Reduction, Society, Health

PREFACE

This project has been carried out as a master's thesis for the master in Product Development at Chalmers University of Technology. The work has been conducted by two students at i3tex AB from September 2016 to January 2017. There are many people we would like to thank for supporting us throughout the project and our years at Chalmers University of Technology. To keep it short, we would like to say as elite athletes usually do: You know who you are.

We would like to especially thank our supervisor Niclas Gustafsson for all the valuable advice and support throughout the project. We would never have been able to achieve as much without the positive support and valuable feedback. We also had the fortune to get to know our colleagues at i3tex which were incredibly welcoming, helpful and allowed us to participate in an particularly fun team building exercise where we modified and raced an endurance car.

We would also like to thank our supervisor Lars-Ola Bligård at the Product and Production Development department at Chalmers University of Technology who was always available for a discussion and gave great advice regarding the interesting ACD^3 methodology.

And also thank our supervisor Leif Sandsjö for giving us valuable advice and direction in the project, without the help, this project would have been a much greater challenge.

Finally, we would like to thank our loved ones for always believing in us, motivating and pushing us, thank you for always being by our sides.

Christofer Persson & Daniel Kuzet,
Gothenburg, January 2017

LIST OF ABBREVIATIONS

ARV = Average Rectified Value

EMG = Electromyography

sEMG = Surface Electromyography

FFT = Fast Fourier Transform

FMT = Functions Means Tree

MDF = Median Frequency

MNF = Mean Frequency

MVC = Maximum Voluntary Contraction

MVE = Maximal Voluntary Electrical Activation

RSI = Repetitive Strain Injury

U. & E. m. = Ulrich & Eppinger methodology

ACD^3 = A methodology where focus lies in iterations in the development work

WMSDs = Work-Related Musculoskeletal Disorders

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1 INTRODUCTION

This report is a part of a Master's thesis that was conducted together with i3tex AB. The purpose was to investigate how work related muscular injuries could be avoided by developing a product which can predict muscle injuries and minimise sick leave. i3tex is an engineering consultant company and works within many industries, one of them being medical technology. The first chapter of the report presents the background, states the purpose and aim and some limitations which have been set in the project.

1.1 Background

The sick leave in Sweden is increasing, and not just the amount of days people are off work but also the number of people that are on sick leave. As of April 2015, the sickness benefit number had increased by 13% by a year (Försäkringskassan, 2015a). This is a concern for the country as it is deteriorating the health of the Swedish population and having a significant cost for the society (Försäkringskassan, 2015a). The most common reason for sick leave in Sweden are the load factors which originate from harmful work postures and movements. Therefore, i3tex wanted the authors to explore and lay the groundwork of the development of a concept which could potentially reduce the amount of sick leave caused by physical injuries. This project will hopefully be a base for the future development of a product which would be sold by i3tex in the future.

By monitoring musculoskeletal status in work environments, and notifying the user when potential harm could occur, the risk of muscle injury and sick leave could be minimised. The data collected by measuring muscular activity could also give a company valuable information of how production lines could be modified to better fit the employees. By minimising the muscle injury risk, the company would potentially have fewer workers on sick leave and the workers would have fewer muscle injuries. A common technique used for evaluating and recording the electrical activity in skeletal muscles is Electromyography (EMG) which will be presented in greater detail up in this report.

1.2 Purpose and aim

The purpose of this project was to investigate the possibility of reducing sick leave, by minimising the most contributing cause, which was work related muscle injuries. The main purpose was to utilise EMG technology, identify suitable muscle status analysis methods, generate concepts and set appropriate technical specifications. The aim was to lay the groundwork for a product concept which the company i3tex will continue developing. The groundwork consisted of developing a signal processing method to analyse muscle status, the design of the different parts of the concept and a technical requirements specification for the future development of the product.

1.3 Limitations

Both the field of muscular activity monitoring and the human musculoskeletal system in itself is a broad and advanced area, and therefore the following limitations were decided:

- To utilise existing EMG technology and signal analyses for the musculoskeletal health monitoring.
- Measuring the most commonly injured muscle.
- Measurements will be conducted on replicated working task movements from observed production sites.
- Measurements of large groups of people will not occur, only a small selection of individuals will be measured for proof of concept and therefore no statistics of significance can be collected from the measurements.

1.4 Report outline

This sub-chapter presents a summary of the contents for each of the chapters in the report.

Chapter 1: The first chapter of this report gives an introduction to the project. A short background of the sick leave problem can be found and this chapter also includes the purpose and goal as well as the limitations of the project.

Chapter 2: The Second chapter aims at helping the reader gain needed knowledge of the central parts of this project. It starts off with a simplified explanation of how the human muscles work before explaining the functionality of electromyography. The final part of this chapter consist of an injury report stating the most common reasons for sick leave in Sweden and how they occur, it does also state the most common parts of the body to injury. Finally, it introduces a hypothesis which has been used throughout the project.

Chapter 3: The third chapter describes the development process of this project with all its phases. It also introduces and describes the tools and methods used within this project.

Chapter 4: In the fourth chapter, the reader can see the results of the project. The results being the different concepts and lastly, a final chosen prototype is presented.

Chapter 5: In the fifth chapter, the project work is discussed, questions such as if the project aim was fulfilled or not, and if the project could have been done in any other way are lifted. The reader can also find future recommendations in the end of the chapter

Chapter 6: The final chapter of the report is a conclusion of the project. It aims at putting the findings of the project into a larger context and reflecting on what conclusions that can be drawn from the project.

2 THEORY

The human body is complex and can be challenging to understand and work with, therefore a theory chapter has been written. This chapter aims to aid the reader with basic knowledge about the functionality of human muscles and the way electromyography (EMG) technology basically works. It also includes an injury report that describes the sick leave situation in Sweden, the most common causes of injuries and how they occur.

2.1 Muscles

There are three types of muscles which the human body consists of. These are the skeletal, cardiac and smooth muscles, all with different purposes for the locomotion of the body. Their activity can be categorised by either being voluntary or involuntary and this project will focus on the skeletal muscles which are controlled voluntarily. These muscles are attached to bones and create the force needed to perform skeletal motion and maintain posture (Kenney et al., 2015).

Muscles can be divided into two different types which differ in regard to the metabolism and function. Slow twitch muscle fibres, are used mainly for long-term work (such as standing up) and do not fatigue quickly. Then there are the fast twitch muscle fibres which are used mainly in high force operations or when working with rapid, short-term movements (such as jumping), which do fatigue quicker than the slow twitch muscles (Kenney et al., 2015).

Muscle force is created by the shortening of the muscular fibres. This is initiated by the brain, which sends a signal that travels down the spinal cord to a motor unit. A motor unit consists of a motor neurone cell body (or α-motor neurone), which is located in the spinal cord, and the axon, which is connected to muscular fibres via axon terminals (see figure 2.1). A single motor neurone cell body and all the muscle fibres it directly signals is called a motor unit. Dependent on the precision of the muscle, the number of motor units will vary. For muscles which require great precision, each motor unit will have fewer muscle fibres to connect to and vice versa with muscles that require less precision (Kenney et al., 2015).

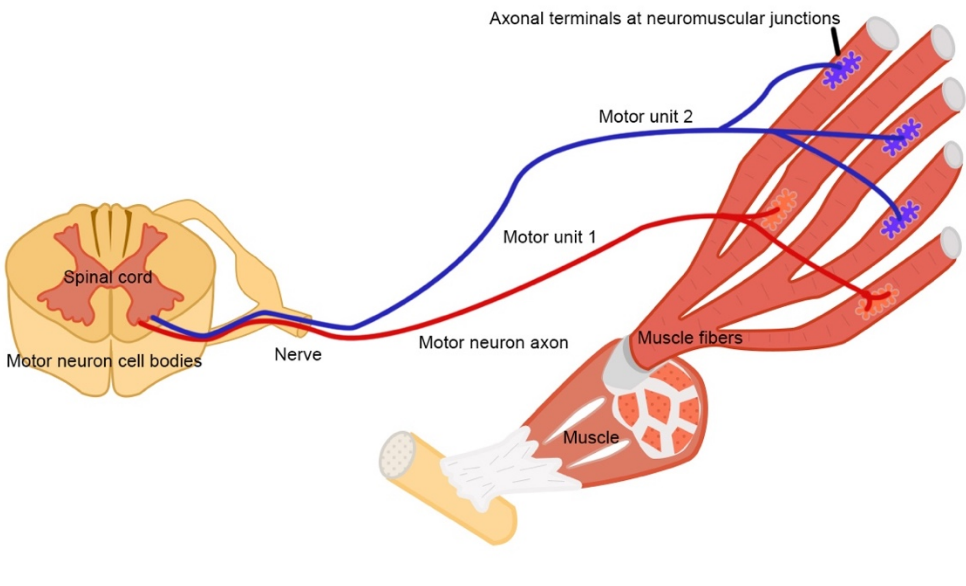

Figure 2.1: Illustration of the muscle and how it is connected to the spinal cord. (inspired and redrawn from the book: Essentials of human anatomy and physiology (Marieb, 2011, p.296)).

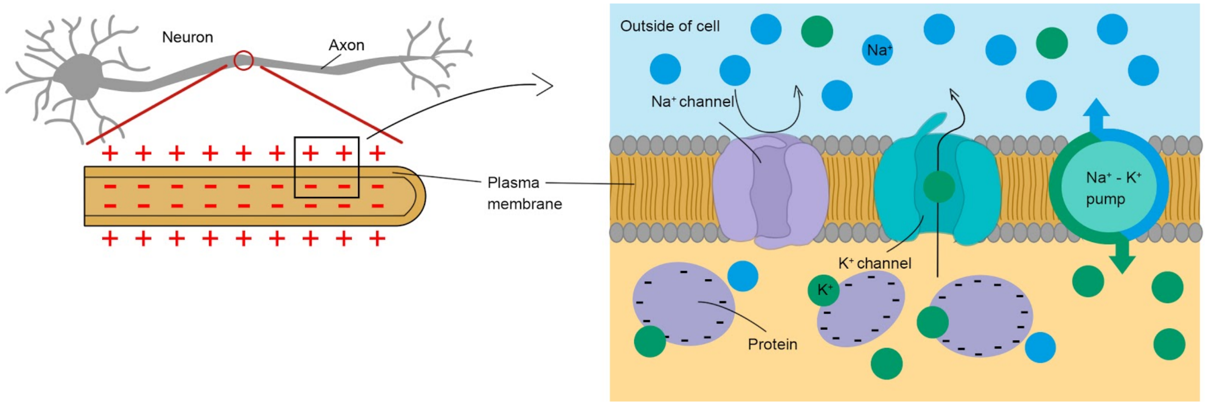

Figure 2.2: Illustration of the action potential. (inspired and redrawn from the book: Essentials of human anatomy and physiology (Marieb, 2011, p.399)).

The way the muscles contract is by receiving an action potential, this illustrated in figure 2.2. The effect is caused by the neurones release of Acetylcholine (a chemical signal) which in turn opens ion gates in the muscle cell membrane, permitting sodium (Na+) to enter the muscle cell in order to depolarise it. If enough depolarisation has occurred, an action potential is produced and the action potential travels along the plasmalemma, through the transverse tubule system which releases calcium ions from the sarcoplasmic reticulum. The calcium that is released binds with troponin which in turn moves the tropomyosin molecules off of the myosin-binding sites on the actin molecules and this allows the myosin heads to bind to them. When a sturdy binding state has been set with actin, the myosin head will tilt and pull on the thin filament past the thick filament (see figure 2.3 for an illustration). (Kenney et al., 2015). Depending on how many of the myosin heads and how often they pull, this will control the intensity/force of the muscular contraction, an example of a muscle contraction when flexing the elbow can be seen in figure 2.4. (Kenney et al., 2015; Webster, 2010)

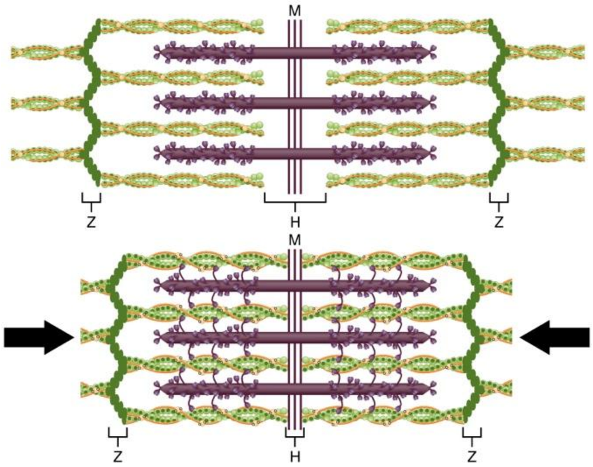

Figure 2.3: Myosin heads of a relaxed muscle (top) and a contracted muscle (bottom), (Upload.wikimedia.org, 2017).

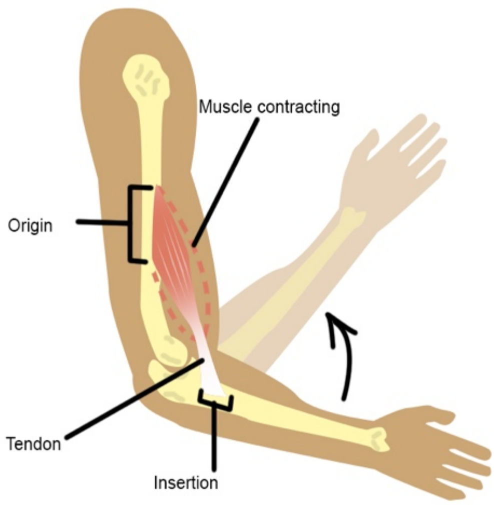

Figure 2.4: Illustration of a muscle contraction when flexing the elbow. (inspired and redrawn from the book: Essentials of human anatomy and physiology (Marieb, 2011)).

2.2 Electromyography

Electromyography is the measurement of the electrical activity caused by the action potentials in the muscles. The signal is the super-positioning of action potentials in close proximity of the area being measured. As the number of motor units exciting action potentials increase, more and more muscular fibres will contract and the muscle force will grow, this will result in a greater EMG reading. (Merletti and Parker, 2004)

EMG can be measured in different ways, one way is utilising needles to get readings from inside the muscles and another way is with surface electrodes placed on the skin in close proximity to the muscle. Needle EMG technology is used primarily to check the health of muscle and nerves because the needle only picks up a signal from a very close proximity.

Surface electrodes, or sEMG, is a technology which does not require skin penetration but requires a good connection to the skin (measured with impedance). Often it is essential to prepare the skin by scrubbing them of dead skin cells, shaving off eventual hair and cleaning the skin with alcohol before applying the surface electrodes. Other difficulties with sEMG is the effect of fat tissue and input from other muscles nearby as they can disrupt the signal *(Interviewee B).* The EMG signal is displayed below in figure 2.5, the muscle is contracted on the left side of the plot (marked red) is and relaxed on the right side (marked black). What can be seen on the right side is noise coming from the heartbeat.

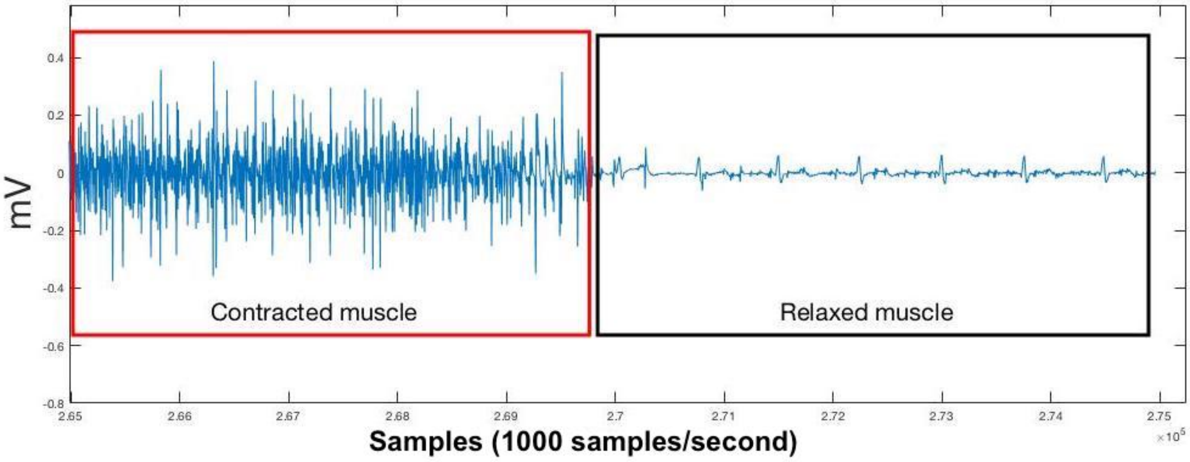

Figure 2.5: Illustration of sEMG signal of contracted muscle (left) and relaxed muscle (right).

Maximal voluntary contraction (MVC) is a measure of force or torque around a joint exerted by a muscle. The myoelectric (ME) signal at a certain %MVC level is highly dependent on several physiological factors such as the diameter of the muscle fibres, number of MU's in the muscle and the rate of which they fire in the observed muscle. This means that with comparable %MVE, small muscles will, on average, have more complex signals than large muscles. The maximal voluntary electrical activation (MVE) is the maximal amplitude the ME signal can reach, for a certain muscle and individual, which is expressed in percentage. The MVE can be found by getting the user to perform a few MVCs to find the MVE. (Merletti and Parker, 2004)

Measuring activity level of muscles is usually done by monitoring the root mean square (RMS), which is the square-root of the mean of the squared signal or average rectified value (ARV), which is the average of the absolute value of the signal (Sandsjö, 2004).

The progression of fatigue can be observed with median (MDF) and mean (MNF) frequency shift, and a signal amplitude increase over time with isometric exercises according to De Luca (De Luca, 1984). The theory states that the MDF and MNF shifts towards lower frequencies and the signal amplitude increases as the muscles fatigue more. With this analysis, it is possible to distinguish between when the muscles are genuinely fatigued from when they are not, for example when an individual does not feel like contracting their muscle. This is easier to detect in controlled, laboratory environment, but harder in real world situations due to the many factors which contribute to changes in amplitude and frequency in the EMG signal (Sandsjö, 2004). The amplitude increase was not always as prevalent as the frequency shift according to the book: The ABC of EMG, and the amplitude increase might be better suited for other applications such as proving the efficiency of training exercises and therefore focus will not be to observe amplitude change in this project. Below in figure 2.6 is a schematic illustration of theoretical fatigue progression, seen with the MDF shift (MNF progression works basically in the same way). The data displayed is for illustrative purpose and is not to be taken as actual measurements from muscles (Konrad, 2005).

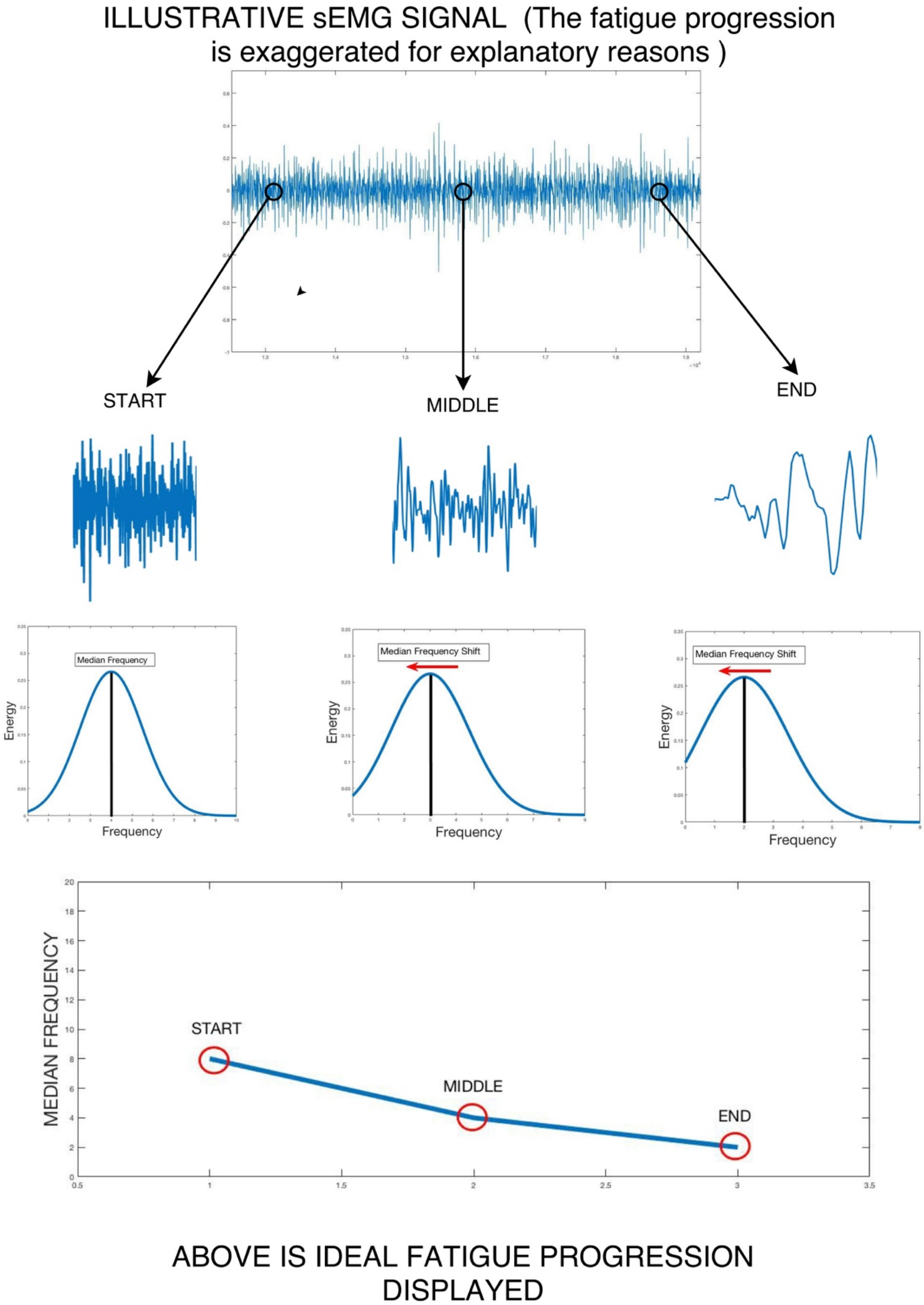

Figure 2.6: Illustrative sEMG signal (inspired and redrawn from the book: The ABC of EMG (Konrad, 2005, p.51)).

The definition of MDF is a frequency value where the EMG power spectrum is divided into two regions with an equal integrated power and can be expressed as below. *Pj* is the EMG power spectrum at a frequency bin *j* and *M* is the length of frequency bin.
(Thongpanja et al., 2013)

$$\sum_{j=1}^{\mathrm{MDF}} P_j = \sum_{j=\mathrm{MDF}}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j$$

The definition of MNF is an average frequency value that is computed as a sum of the product of the EMG power spectrum and frequency, divided by a total sum of spectrum intensity. And can be expressed as below, where *fj* is a frequency value at a frequency bin *j*.
(Thongpanja et al., 2013)

$$\mathrm{MNF} = \sum_{j=1}^{M} f_j P_j \Bigg/ \sum_{j=1}^{M} P_j$$

2.3 Injury report

This subchapter describes the worrying sick leave situation in Sweden and the most common causes such as injuries and diseases that lead to sick leave. Also described is how the injury or disease leading to sick leave may occur. Finally, the Cinderella Hypothesis is described and will be of great importance for the rest of the report.

2.3.1 Sick leave in Sweden

In Sweden the sick leave is increasing, as of April 2015, the sickness benefit number had increased by 13 % over the last year (Försäkringskassan, 2015a). Not only are the short sick leaves increasing, the longer sick leaves are increasing as well, between 2010 and 2013 sick leaves that are longer than half a year had increased by 9 % (Försäkringskassan, 2015b).

The Swedish Work Environment Authority's study from 2014 showed that almost one out of four (24%) employees in Sweden had felt discomfort as a result of work (The Swedish Work Environment Authority, 2016). Load factors are one of the most common causes for sick leave in Sweden, actually, it is the most common cause of occupational diseases, underlying 40% of all reported occupational diseases, and one of the most common causes for work related accidents (The Swedish Work Environment Authority, 2015).

The average length of sick leave for men and women with load-related occupational diseases is three months (Prevent, 2016). Over a five-year period (2009-2013) load-related work accidents leading to sick leave have increased with 28% in Sweden, at the same time load-related occupational diseases have increased with 6% (The Swedish Work Environment Authority, 2014b).

The difference between load-related accidents and diseases can be described as; anyone who suffered a load-related work accident can usually say exactly when it occurred, while discomfort which has occurred over a longer amount of time are considered as load-related occupational diseases (The Swedish Work Environment Authority, 2016).

2.3.2 Work-related musculoskeletal disorders

Load factors usually lead to work-related musculoskeletal disorders (WMSDs) also known as repetitive strain injuries (RSIs), even though the name does not accurately describe the disorders since it only suggests that repetition causes the disorders. Work-related musculoskeletal disorders are a medical term for symptoms which originate from the musculoskeletal system, and these are the muscles, tendons and nerves. It can be difficult to distinguish a work-related injury from other causes of symptoms since they can occur over a long period of time, and therefore it may be difficult to prove that the injury is work-related (CCOHS, 2016).

Work-related musculoskeletal disorders are often caused by monotonous and repetitive work with local loads (muscle fatigue) that are large and one-sided. It may also be the result of sedentary work and work in front of a computer and psychological factors such as stress, since this may lead subconscious tension of neck muscles for instance. The variety of causes and the time spectrum shows the difficulty of identifying where the injuries have occurred. The most common reason of load-related work accidents is heavy lifting, carrying or getting up. This category stands for 40% of the injuries. The most common reason for load-related occupational diseases is repetitive work (21%). Therefore, it may not come as a surprise that the vehicle manufacturing industry group has the most load-related occupational diseases with 4.30 individuals for every 1 000 employees (The Swedish Work Environment Authority, 2014b). This stems from working tasks at a production line often can be monotonous and repetitive as well as include heavy lifting (The Swedish Work Environment Authority, 2014b).

2.3.3 Common body parts to injure

Work-related musculoskeletal disorders include three types of injuries namely; muscle injuries as well as tendon injuries and nerve injuries (CCOHS, 2016). The most common body part to injure at work for both men and women is the back (7,1% for men and 8,4% for women) followed by the shoulders and arms (4,2% for men and 7,1% for women), this can be seen in figure 2.7 below. For men, the third most common injured body part are the legs (2,2%) while for women it is the neck (4,9%). For women, the three most commonly injured body parts are quite clear as the third most common body part namely the neck is followed by the hand/wrist, for men this is less clear since the third most common body part (legs) are closely followed by the neck and hand/wrist. This means that it can be of importance to look at those body parts for men as well (The Swedish Work Environment Authority, 2014a).

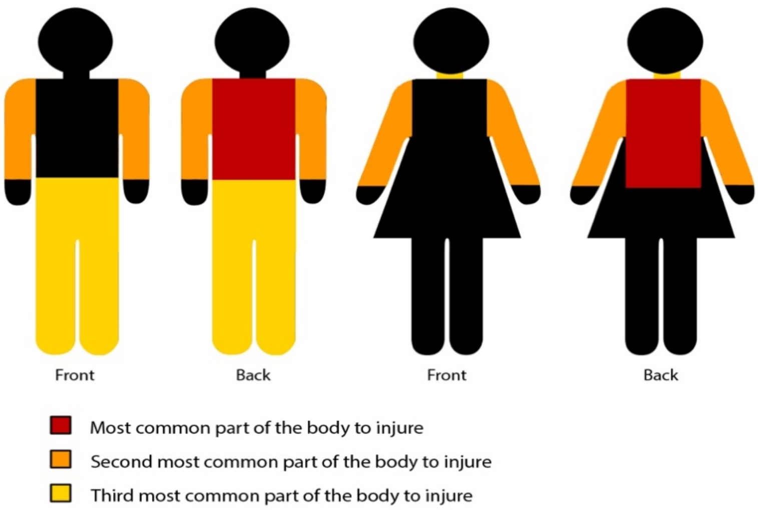

Figure 2.7: Illustrates the most common parts of the body to injure.

2.4 The Cinderella Hypothesis

The Cinderella Hypothesis postulates that when a group of muscle fibres are not given enough time to recover by resting, damage can occur. One way of discovering if muscles need rest is by monitoring fatigue, another is activity level of the muscles. The name comes from the story of Cinderella which always had work and was never given any rest. The damaged muscle fibres can become a source of pain. Low intensity, continuous activation of the muscle fibres can be done consciously when typing for instance, but it can also be done subconsciously due to tension derived from stress. (Zennaro et al., 2003)

This hypothesis is a key element in this project because the authors argue that muscle fatigue level and muscle activity can be viewed as an indication of when muscles need rest in order not to get injured. The major challenge in this project was identifying a threshold of muscle fatigue level which would prevent muscle harm and also find muscle activity levels which are actually harmful.

This challenge could be solved by collecting enough muscle activity/fatigue data and correlating the data with user health status inputs to identify harmful activity/fatigue thresholds. These thresholds would be implemented into the concept at a later stage when a statistically valid amount of data has been collected.

2.5 Theory summary

The key theory elements for this project are listed below:

- The muscles are complex and differ significantly in terms of function, health status, size and so on. Therefore, it is a challenge to measure their activity with a measurement tool, such as a surface electrode.
- Typically, in order to achieve a good connection, with low signal noise, between an electrode and skin, preparations are required, such as removing dead skin cells, shaving off eventual hair and cleaning the skin with alcohol.
- Noise can cause wrongful analyses of the signal which might lead to wrong results in the end.
- Cinderella hypothesis states that if muscles are not given enough time to recover, muscle injuries can occur.
- Monitoring MVE and RMS gives an indication of the activity level of the muscle.
- The fatigue progression of muscles can be seen with a median and mean frequency shift from the sEMG monitoring.
- Sick leave is increasing and the main contributor is work related injuries.
- Work related injuries often occur due to long term load factors which originate from harmful work postures and movements.

3 DEVELOPMENT PROCESS & METHODS

This chapter describes the project's development process and all its phases. The development process was a combination of methodologies and consists of multiple phases. The work began by identifying and investigating what measuring methods and equipment were available for measuring muscular activity with EMG and how well they were suited for a future product. Furthermore, the most common muscle injury areas were investigated to identify an efficient way of collecting data. The work then proceeded by developing a product concept which utilised EMG technology while being easy and comfortable to use while same time does not obstruct the user in their work task. Knowledge gathered from this work would act as support to further improve the health of the workforce and to help companies develop ergonomically correct workplaces.

The development process was a key part when it came to creating a product out of the identified opportunity. This part of the project can be challenging to handle due to its unclearness in the beginning, as well as all the choices which derive from the development process creativity. The project used a combination of Ulrich & Eppinger methodology (U. & E. m.) and the ACD^3 process. The methods are suited for the development of novel products, which this project aimed for. The ACD^3 process is adapted to work together with other product development methods and a combination of the two was made (Bligård, 2015a). This was done due to time limitations and the need to expand the information collection duration because of the authors biomedical engineering knowledge gap (Bligård, 2015b). Below is a figure (figure 3.1) displaying the overall development process used in this project.

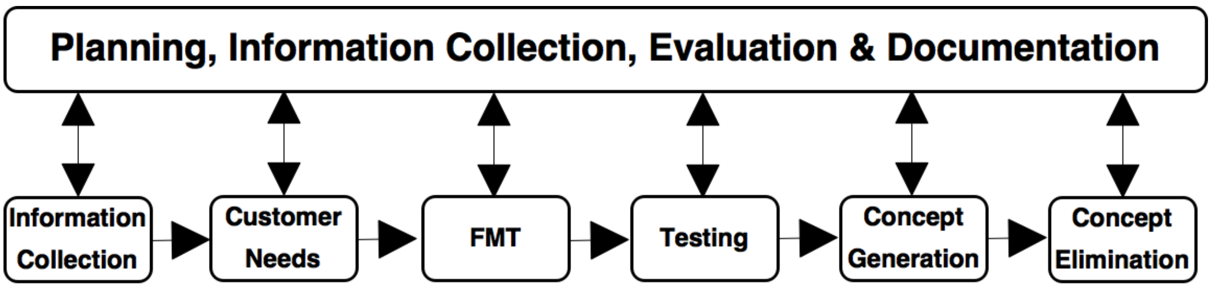

Figure 3.1: the overall development process used in the project.

3.1 Information collection

Before starting the concept generation stage, a key point was understanding what needed to be developed, what challenges would arise and how these would be met. This was done by an extensive literature study, analysing test data and expert consulting.

3.1.1 Injury report data

The injury report presented earlier in the report (chapter 2.3) acted as support in identifying what part of the human body to focus on in the project. The idea of the project was to develop a feasible product while keeping the cost down, and therefore it was crucial to keep the complexity of the product at a reasonable level. This was done by selecting the most common injury areas on the human body to work with, and later discuss these with experts. The injury reports played the role of finding harmful work movements in order to replicate them in the dynamic tests later on in the project.

3.1.2 Literature study

A large portion of the project time was spent in gathering information about EMG technology and the human musculoskeletal system. This was done because the authors had limited knowledge of biomedical engineering and this was crucial to aid the development of a novel biomedical product. The literature study indicated a clear difficulty in developing a product which would predict muscle injury in a work environment. This was because no reports were found to solve the challenge of analysing sEMG signal and predicting when muscle injuries would occur in a non-controlled environment.

3.1.3 Expert consulting

External information search was mostly done with expert consultation. Three experts wished to remain anonymous and therefore are named as interviewee A, B and C were interviewed to identify challenges, opportunities and a suitable area of the body to measure musculoskeletal fatigue progression and activity levels. Challenges brought up in the expert/doctor interviews was the difficulty in extracting accurate assessments of musculoskeletal health in dynamic environments, such as for instance working conditions. The major reason being that the data collected from workers would not be comparable, as the forces and movements would not be identical for each task repetition. The key learning points gathered from the interviews are presented below, and some of the points acted as problem identifications.

1. The muscles around the shoulder blades, especially the trapezius muscle were confirmed as the muscle to focus on when monitoring the muscle activity.
2. It is important to minimise signal noise in order to extract useful data.
3. The importance of reference movements to ensure comparable data.
4. Monitoring and collecting data over a long period of time is crucial for statistical validity. This was recommended in order to see trends of muscle fatigue and map it against actual sick leave and with this continue the development of the product so it can predict injuries with the support of statistics.
5. Consider the placement of EMG electrodes to minimise the risk of signal disturbances due to skin-to-electrode movement (Webster, 2010).
6. Impedance check should be implemented into the product as it is a useful measurement of the connection quality between skin and electrode. The challenges to overcome in order to control the impedance is the effect of body fat, sweat, body hair and the movements by the user.
7. Crucial to develop a product which will not affect the user's ability to move freely, as for instance cables can do.

3.1.4 Focus area

In the beginning of the project, the authors had an initial idea of a product which would be able to analyse several muscles in the body, but after the expert consultancy, the focus was narrowed down. This was due to the problem of having to develop an overly complex product within the timeframe, and therefore only one muscle group was focused upon. The trapezius skin area is a part of the body which generally sweats less than other parts of the body, then like for instance the lower back or the neck area does, according to the expert interviewee A.

The muscle is useful to measure in both physical and psychological point of view as it is dependent on workload and stress level. As individuals get more stressed, they tend to lift their shoulders with the trapezius muscle, and this can be measured with EMG in order to draw conclusions about the muscle health according to the expert interviewee A.

3.1.5 Current technology status and patents

No competitors were found to fulfil the project goal. Products on the market which utilised sEMG technology were developed to measure the activity level of muscles for exercise purposes and did not warn users of long term muscle injuries. One product was found that not only focused on exercise and sports but also ergonomics, was named Heddoko (Heddoko, 2017). However, the product did not use sEMG, instead, the product utilised motion capture sensors and analysed movements and posture. Products which were found to analyse the health of muscles utilised needle EMG and were primarily used to find existing muscle and nerve disorders. These findings indicated that the development of a product which would fulfil the project goal could be challenging as no company had succeeded in this task.

EMG is a mature technology and therefore focus lies on developing smaller and more powerful products. The state-of-the-art EMG exercise monitoring products today consist of relatively small sender/receiver modules (approx. 10x10x4 cm), cables and electrodes sewn into clothes, and an external computing unit. These products analyse the activity level of muscle EMG with unknown signal quality. A common way to acquire a good signal quality is by utilising Ag-AgCl electrodes due to their good connectivity between skin and electrode, but this technique requires skin preparations and are usually found in laboratory environments as they obstruct the user with cables.

As EMG is a mature technology, many of the patents found were out of date, and the most relevant patents in regard to this project were found within the sports and exercise segment. One of these was an electrode patent which presented an sEMG electrode which was sewn into a fabric. The electrode did not require any skin preparations to achieve good skin to electrode connection while at the same time being machine washable and reusable. This was a state-of-the-art electrode technology and showed the authors what was possible What needs to be considered with the patent was the lack of information about the signal quality achieved with the electrode (MAD Apparel, Inc, 2015; Athos, 2016).

3.2 Customer needs & requirements

The majority of the requirements were gathered from interviews with experts and doctors as well as sending out a questionnaire to 44 individuals in different business sectors, seen as potential future customers. The customer needs were translated into product specification sheet according to Ulrich and Eppinger (2012).

The semi-structured, exploratory questionnaire was sent out and 44 responds were received with a broad job type demographic. In figure 3.2 below the left chart shows the distribution of the demographic job type, the middle chart shows the distribution between female and male responders and the right chart shows the age distribution of the responders (can also be seen in appendix A).

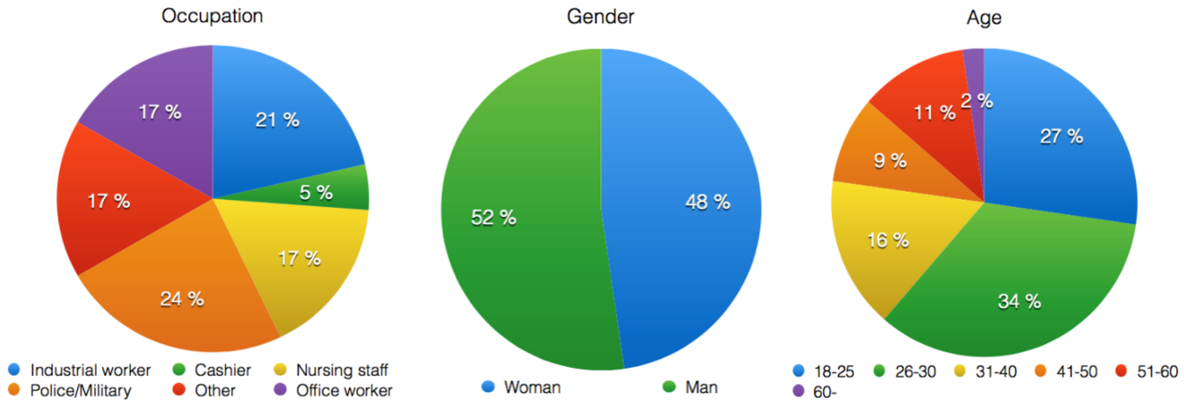

Figure 3.2: The demographic distribution of occupation (left) as well as the demographic distribution of gender (middle) and the demographic distribution of age (right).

The diversity in the demography of the data indicates no shift towards any particular group of people, resulted in a broad needs mapping, suited for the project. The semi-structured questionnaire collected information about the musculoskeletal health of the individuals and proceeded with questions about their perceived needs from a future product.

3.3 Functions Mean Tree

The complexity of an everyday usable sEMG product meant a Functions Mean tree (FMT) was necessary to create (figure 4.1). FMT divides the product into smaller elements/functions (challenges) which are easier to grasp and to work with. The future product was divided into functions and sub-functions which act as all the sub-functions required to have a complete product. As seen in figure 4.1 the tree consists of two types of boxes, the functions which need to be fulfilled and are symbolised by the rectangular boxes, while the means are symbolised by the ellipse boxes. (Almefelt, 2016)

3.4 Testing

In order to make valid decisions later the project, a few tests and verification methods were needed. These tests were conducted to explore the possibilities and limitations of the De Luca theory. The results of the tests are presented in the Final Design chapter in this report since they will be the base of how the final concept will work.

3.4.1 The sEMG measuring equipment

Two different EMG measuring equipment were available in the project, one which used a simple way to analyse muscle contractions and another which could perform more advanced analyses.

The simpler equipment illustrated in figure 3.4, made by V/T Software HB, analysed the EMG signal by monitoring the amplitude of the signal to alarm the user. When a %MVE threshold was reached and kept at or above that level, a delay timer would count down and alarm the user. The %MVE threshold level and the timer were set by adjustment knobs and it was up to the operator to decide appropriate levels, basically by guessing. This equipment was designed to alarm users of harmful postures and body movements, but no actual analysis was done in terms of the health or fatigue level of the muscles. This simple equipment acted as a learning tool to understand basic sEMG functions.

Figure 3.4: The simpler equipment used in the project.

The advanced equipment, shown below in figure 3.5, was made by BioPac Systems, Inc and named MP36, could record and condition multiple signals from muscles, heart, brain, eyes and more. The MP36 had built-in filters to eliminate unwanted ambient noise and came with a computer with software to analyse EMG recordings and perform settings.

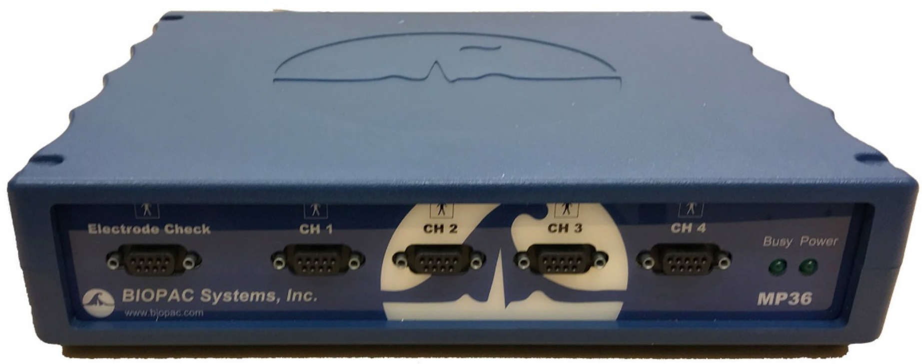

Figure 3.5: The MP36 system made by BioPac Systems Inc.

In order to minimise the risk of working with compromised data due to equipment errors several clinics, universities and workplaces were contacted and asked to lend out sEMG equipment to assist the project. None were able to supply with any sEMG equipment at the time of the project and this meant that results would be difficult to verify at the end of the project.

3.4.2 Planning of the dynamic test procedures

The following step was to decide a data collecting test procedure in order to ensure consistency between subjects. A test protocol (Seen in the appendix H) and a questionnaire for the subjects was created and used for the tests. The tests were performed with dynamic exercises and every test was initiated by removing dead skin cells with abrasive pads and cleaning the skin of the subject and to ensure low impedance connection between skin and electrode. sEMG electrodes were placed on the upper trapezius muscle and a reference electrode between the left and right upper trapezius muscle (on the C7 Spinous process area).

The test protocol stated:

- The purpose of the tests.
- Materials needed to perform the different tests.
- Desired number of subjects.
- Duration of each test.
- What should be recorded.
- The setup of the mock-up environment.
- The setup of the EMG equipment.
- Answering a short questionnaire about physical health prior tests.
- Information to the subject of how to perform each test, for example, each step in the “Assembly of a car door” test.
- Description of sEMG electrode placement.
- Video recording setup.
- Recording of reference EMG signal.
- Recording the EMG signal.
- Initiate the working tasks.
- Recording the resting EMG signal.
- Answering a short questionnaire about their physical health post- tests
- Analyse results.

3.4.3 Dynamic Tests

The initial goal of the dynamic tests was to explore the possibility of measuring the progression of musculoskeletal fatigue during dynamic movements. The data would be used to optimise the sEMG data analysis in order to adapt it to a working environment where the user would be notified of the muscle health status. This would later show to be very challenging and another approach was necessary.

Using the advanced measuring equipment, the test protocol was followed in a verification purpose and data was collected for three separate tests. The tests revealed certain aspects which were not considered during the design of the test protocol due to the nature of the dynamic movements. One was the need of a timing indicator which would help the subject perform the exercises at a certain tempo in order to get comparable data. Another aspect to solve was the need to ensure that the subject would exert the same force for each repetition because large variation would not allow the data to be comparable. The first challenge was solved by using a metronome, set to 2 beats per 20 beats per minute, and movements were synchronised the metronome, which can be seen in figure 3.6 below. At the first beat the subject should have relaxed muscles (picture to the left) and at the second beat the muscle should be loaded (picture to the right). This exercise was repeated for a number of repetitions, then in order to separate the sets and to give some rest to the subject, the muscles were relaxed for 4 beats before next set was started.

Figure 3.6: Subject performing the dynamic test.

3.5 Concept Generation and Elimination

When creating a new type of product, the concept generation is very interesting, since all gathered information and knowledge is used in order to try and create something new. The following sub-chapters will explain how the concepts were generated. In chapter 4.2 the concepts which did not make it to detail design are given a short introduction and explanation to why they did not go further in the development process. As for the concept which made it to the final design phase, it is described in chapter 4.5.

Throughout the concept generation, the five-step process from U. & E. m was used to systematically find the best solution (Ulrich and Eppinger, 2012).

1. Clarify the product.
2. Search externally.
3. Search internally.
4. Explore systematically.
5. Reflect on the solutions and the process.

As mentioned in chapter 3.3, an FMT was used to divide the product into smaller functions and sub-functions. The first step of the concept generation was to have a brainstorming session where potential solutions for each of the functions and sub-functions. The brainstorming sessions were the main tool for the internal search. The project members got 20 minutes per function (from the FMT) to come up with as many possible solutions each function. Important for this part of the concept generation is to remember that no solution was considered worthless because each solution could give inspiration to other solutions. When 20 minutes had passed, the authors met up again to present their ideas to each other and discuss. When this was done for all the functions, the members were encouraged to take a look at the solutions and functions separately and see whether they could come up with any more ideas. These ideas were presented a couple of days later. The next step was to put all of these solutions into a morphological matrix in order to extract as many concepts as possible (Almefelt, 2016).

Even though smart textiles have a great potential when it comes to the development of a comfortable wearable product, smart textiles were not considered in this project. This since smart textiles have not been developed to a degree where they can be used in this type of product. Instead, the focus was on developing a comfortable product which would not be in the way for the user.

3.5.1 Concepts

The next step after conducting the brainstorming sessions was to use the morphological matrix in order to create a large number of concepts by combining the sub-solutions from the matrix.

3.5.2 Concept Elimination

The generated concepts from the previous step in the project were evaluated and boiled down into one winning concept. There are several ways in selecting a winning concept, such as presenting them to customers for selection, prototypes built to base selection upon test data, web-based surveys and so on. Due to time limitations, quick elimination steps were essential to keep the deadlines and therefore three suitable matrixes were chosen, which were possible to perform without external assistance.

The first step was an elimination matrix, which acts as a strong filter for the elimination process and can help reduce a significant amount of unfitting concepts (Almefelt, 2016). The criterias which were checked for each concept to find out if they would solve the main problem, fulfil all demands, were feasible, had a reasonable cost, were safe and if there was enough information about them.

In the following step, a Pugh matrix (appendix D) was used to evaluate the concepts according to their strengths and weaknesses against a reference concept (Ulrich and Eppinger, 2012). In order to ensure an unbiased elimination process two iterations were done with different reference concepts. With the two iterations it was possible to see if same or similar results were achieved, if so, then the concepts which had the lowest score could be eliminated. The concepts which passed the second elimination step were then exposed to a third and final step in identifying one winning concept. Before continuing with the next step, improvements were made to the four remaining concepts, based on the learnings from the concept discussions which took part during the two first elimination steps.

The third and final step was to work with a scoring matrix called Kesselring (appendix F). The matrix consisted of several criterias which were given weighting values (Almefelt, 2016). For instance, the criteria of replaceability of parts were given a lower weighting value (for instance a value of 2) than the criteria of how easy the product is to install by the user (for instance a value of 5). The concepts were discussed in terms of how well they were perceived to fulfil each criterion in a scale 1 to 5, these values were then multiplied and a score was generated, then all of the scores, for all the criterias per concept were summed up and an overall total score was generated (Almefelt, 2016). The concept with the highest score was then the winning one.

4 RESULTS

In this chapter, the results of the project are presented. The chapter begins with the translated customer's needs and continues with introducing the different concepts from the concept generation as well as the results from the concept elimination. Then the chapter carries over to the final design stage where the signal processing method is introduced. Finally, the final concept is presented, with all of its necessary sub-parts and also the technical specification of the product which needs to be fulfilled in order for the future product to function correctly.

4.1 Customer needs & requirements

Some of the initial requirements gathered from the questionnaire were broad and wage which required caution in the elimination process in order not to eliminate good concepts in case they did not fulfil all requirements. Most of the requirements were translated from the answers in the questionnaire, but some were also captured while conducting the literature study and from researching present EMG solutions as well as consulting experts. A table over the most important initial specifications can be seen in table 4.1 on the next page, to see the entire initial requirements specification see appendix B.

As the idea with the product was that it should be used every day in order to anticipate work-related musculoskeletal disorders, one of the most important requirements was that it should be comfortable to use. Other requirements were also the importance of it being user-friendly and quick to set up and remove.

From the customer's voice, it was found that it was necessary for the product to enable easy access to the musculoskeletal information and to get it shown visually on a screen or in a mobile application. It also showed the significance of the product being hassle free and wireless.

Since the product ought to be used by people in diverse occupations, it was important that it could be used in a great variety of environments, therefore the product should have an IP class IP67, regarding water, dust and temperature operation. Another requirement which was set for the product was the shock resistance in case the product would come off the user and fall on the ground. As for the size requirements of the product, it was set after conducting a benchmark of other sEMG products. The size requirements were decided with regards to comfort, which in turn translated into the product being as small and light as possible. Certain aspect restricts the size, and in this case it was the electrodes and sender/receiver unit.

A product which utilises sEMG monitoring might have to use reference movements (according to the three experts interviewee A[1], Interviewee B[2] and Interviewee C[3]) in order to capture the progression of muscle fatigue. Therefore, potential customers were asked questions about this in the questionnaire. With the input from the questionnaire, two requirements for the reference movement were set. The first question was what the maximum amount of time the reference movement can take. This requirement was set to less than 30

[1] Meeting with interviewee A, 2016-09-16

[2] Interview with interviewee B, 2016-10-18

[3] Interview with interviewee C, 2016-10-19

seconds with a target level of less than 10 seconds to meet if possible as comments from the survey stated as short time as possible. The second requirement was a question regarding the number of times a day the reference movement could be conducted and still not be considered annoying for the user. The value extracted to be fitting was twice each working day (every 4 hours), while the target value was to only require reference movements once a week (every 168 hours).

Table 4.1: The most important initial specifications.

Initial Specifications: Muscle monitoring product	Requirement	Target	Unit
Comfort			
Comfortable to use	Pass	Pass	Binary
weight of the product	500	300	gram
Product thickness	x ≤ 15	x ≤ 10	mm
Product depth	x ≤ 20	x ≤ 10	mm
Product length	x ≤ 20	x ≤ 10	mm
Provide hassle free link	"wireless" with wires on sensors	completely wireless	pcs.
User Friendly			
Intuitive to use	Pass	Pass	Binary
Function with low amount of gel	Pass	no gel	Binary
Transmit result from sensors to monitor	Pass	Pass	Binary
Visual feedback	Pass	Pass	Binary
Reference movement time	x ≤ 30	x ≤ 10	sec
Reference movement, amount of times per week	once every 4th h	once every week	times/h
Washable	Pass (hand wash)	Pass (Machine Wash)	Binary
Pre-monitoring time (from pick-up to monitoring)	x ≤ 5	x ≤ 2	min
Post-monitoring time (from removal to storage)	x ≤ 5	x ≤ 2	min
Ease of locating the correct position	within 1 cm from "best" spot	within 3 cm from "best" spot	cm
Durability			
Complies with IP67 class requirements	Pass	Pass	Binary
Materials are able to withstand outdoor environment	Pass	Pass	Binary
Shock resistance	drop from 1,5 m*	drop from 2m*	m

Having set all the above-mentioned requirements, helped straighten out the winding road of the project and the end goal was a bit clearer.

4.2 Functions Means Tree

The main function of the functions means tree (figure 4.1) was identified as 'Monitoring and analysing muscles'. On the next level, six function groups were identified, and they were the following: 'Information output, 'control product, 'carry parts', 'connect energy', 'capture signals' and finally 'handle signals'. The two most important functions were 'captured signal' and 'handle signal' with three sub-systems each. The remaining functions have two sub-systems each except for 'connect energy' which has only one level. The 'handle' and 'capture signal' groups consisted of three functions each and were solved by 'receive signals', 'interpret signals' and 'send signals'. As for the 'capture signal' group, it consisted of the following systems: 'locate muscular activity', 'register muscular activity' and 'secure at location'.

The information output system was divided into two sub-functions, namely: 'visual information' and 'warn user'. The 'control product' and 'carry parts' were also solved by one mean each which was divided into two sub-functions each. For 'control product' the mean control system is divided into the following sub-systems: 'user information input' and 'start and stop' functions. 'Carry parts' was solved by a chassis, which in its turn is divided into the sub-functions 'hold parts' and 'cover parts'. Finally, the 'connect energy' function is solved by a 'connect system'.

Having the product broken down into smaller pieces, sub-functions and problems became easier to handle and to know what needs to be developed in order to create a working product. After this step, the focus was shifted in finding solutions for the product.

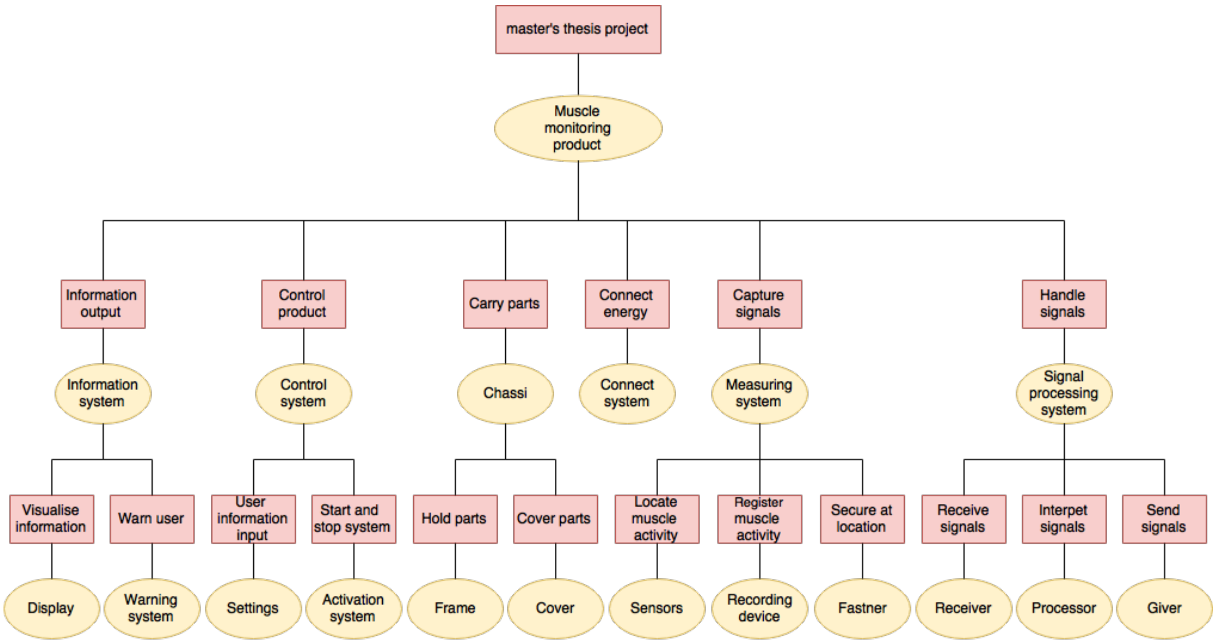

Figure 4.1: The functions mean tree of the system.

4.3 Test results and final signal processing method

In this sub-chapter, the test results and the final fatigue analysis method is presented.

4.3.1 Signal processing and results

This part of the report will show how the sEMG signal can be processed in order to see the progression of muscle fatigue. The end result of the tests and the final signal processing method developed will be the suggested way in how the concept will analyse muscle fatigue. By having the user follow the same exercise as the final testing will present, the concept will be able to see the muscle fatigue progression.

4.3.2 Data analysis

The collected dynamic test data was analysed in order to verify the De Luca frequency shift theory, but in this case, the monitoring was modified to verify if the progression of fatigue can be seen during dynamic repetitive movements. This was done to see if repetitive work movements can be measured and analysed in order to see muscle fatigue progression. The collected EMG signal was saved as .mat files and MATLAB software was used to analyse the data with the medfreq function in MATLAB. A plot (seen in figure 4.2 below) was produced that displays the time-domain EMG signal, and what can also be seen in the plot were the EMG activity for each set, separated by rest (low signal activity). The test was planned to contain 10 repetitions for each set, but this was difficult to control during the first test and therefore errors occurred. As seen in the recording, the “spikes” represent each time the subject lifted the hand. The first test indicated how challenging it can be to perform a reference movement.

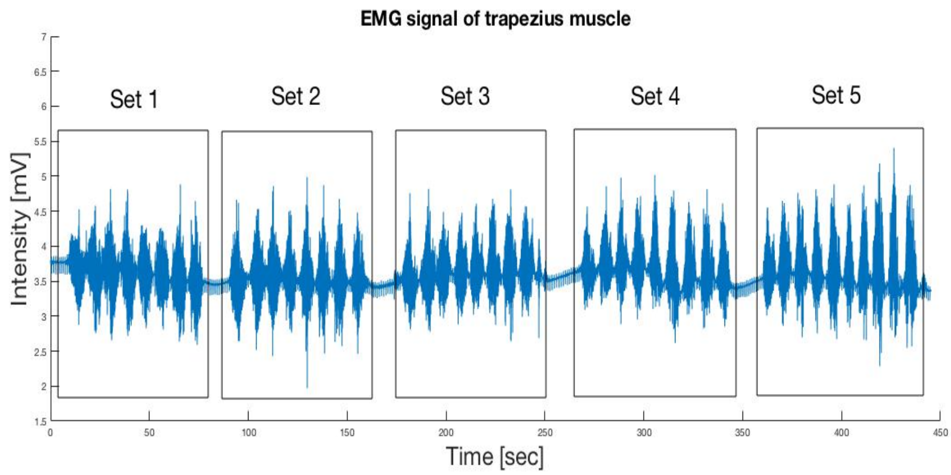

Figure 4.2: One of the first MATLAB plots created, displays the time-domain EMG signal.

The time-domain EMG signal was divided into each exercise set, and MDF and MNF were calculated for each set in order to compare them between sets. The result can be seen in the plot below (figure 4.3):

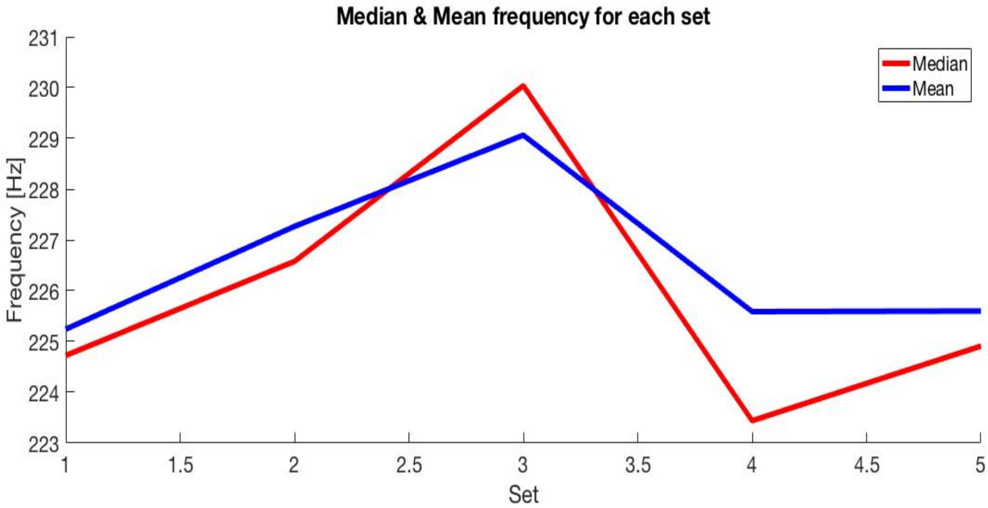

Figure 4.3: Plot that illustrates the median and mean frequency for each set.

The results were not what was expected in regards to the De Luca theory because the MDF and MNF did not clearly shift towards the lower spectrum, and the mean/median values are far to high. Testing continued with different movements such as the “roof assembly” and “saw operation” with different subjects, but neither did these tests show a clear frequency shift. This led the work to continue with identification of possible faults in the testing procedure.

4.3.3 First root cause analysis

Discussions about possible root causes took place after the tests to identify potential areas in the testing which could have affected the results in a negative way. The potential errors could have been variations between sets and repetitions, and it was necessary to minimise these variations in order to produce as comparable data as possible. Therefore, the number of repetitions needed to be kept the same between sets, movements needed to be as identical as possible and the placement of electrodes needed to be correct, as there was a risk of skin disturbance due to skin movement (Webster, 2010). Additional tests were performed, and the results were still not as expected and a different approach was necessary.

4.3.4 Design criteria update

The tests showed the initial idea of fatigue analysis on dynamic movements was very challenging to solve, and in real world applications, would be difficult to achieve. In other words, the possibility to observe muscle fatigue when repetitive work is done was not achieved. A new approach was therefore aimed for, where De Luca’s isometric exercises would be measured to verify the theory. With this, the product concept would utilise isometric exercises to measure the progression of the user in order to notify them.

4.3.5 Isometric tests

The new design criteria led to a modification of the tests where the subjects were seated and their trapezius muscle was loaded by lifting a weight of 2 kg with one arm to 90 degrees' relative to their body. The weight of 2 kg was chosen because this would fatigue the muscles faster than without weight. This position was kept until the subject no longer was able to lift the weight due to muscle fatigue. Four different subjects took part in the tests and they were asked to participate only if they felt that their muscles were well rested prior to the test, to collect the whole fatigue spectrum, from a muscle being well rested to fully fatigued. After the tests, the data was analysed and the frequency analysis showed similar results as previous tests, in other terms, the data did not show any clear muscle fatigue and this needed to be solved.

4.3.6 Second root cause analysis

The following step was to identify why the data did not show the expected results. A potential cause of the problem was identified to be equipment failure with the advanced measuring equipment, therefore, three more static tests were therefore performed with the simpler equipment. When the data was extracted and analysed it was seen that the sampling rate was at 20 Hz, which was far away from the minimum of 1000 sampling rate (Konrad, 2005) required to detect 500 Hz due to the aliasing effect (500hz is a scientific recommendation according to the book: The ABC of EMG (Konrad, 2005)). Expert interviewee A [4]was contacted and a phone meeting was held to identify the potential areas in which could affect the frequency analysis. The EMG data from the tests were plotted and discussed, which resulted in a suggestion to remove the 2 kg weight from the tests as they would interfere with the frequency analysis, so the tests were changed to only have the weight of the arm to act as the load on the muscles. It was discussed that the weight might fatigue the muscle too quickly for it to be detectable in the frequency analysis. Another aspect to consider was that the MDF and MNF were near the middle, approx. 225-250 Hz, of the total 500 Hz frequency spectrum. This indicated that there was some signal noise, and filtration of some sort was necessary because the MDF and MNF should lie around 150 Hz according to Interviewee A and the book The ABC of EMG (Konrad, (2005).

4.3.7 Final testing

The final test was done as accurately as possible by the project members to minimise any procedure errors. Guidelines, called "signal check procedures" from the book: The ABC of EMG were followed to eliminate possible signal disturbances. This skin was prepared with abrasive pads to remove dead skin cells and cleaned with a cloth and a cleaning agent. The electrodes were placed close together on the trapezius muscle (can be seen in figure 4.4 below), both the signal offset and the signal impedance were checked with BioPac software (6.9 and 7.15 Kilo-Ohm for the impedance, can be seen in the picture below). In the final test, electrode gel was used to achieve as good of a connection as possible between the skin and electrode. The signal recording started and subjects the right arm was elevated 90 degrees straight (up to shoulder height) and kept at that position until the subject could no longer keep that posture due to fatigue, which was for approx. 275 seconds). The subject was well rested prior to the test.

[4] Phone conference with interviewee A, 2016-12-01

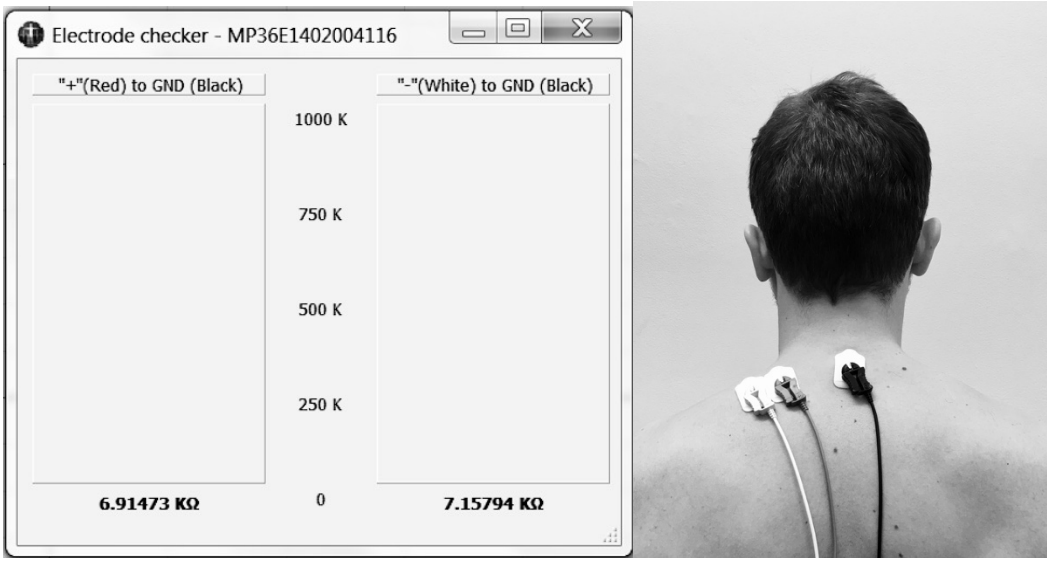

Figure 4.4: the left image shows the impedance of the electrodes and the image to right shows how the electrodes were placed on the subject.

A script was written in MATLAB to solve the frequency analysis challenge. The script transforms the signal from a time-domain into a single sided frequency-domain representation with Fast Fourier Transformation, displayed into two plots below, the first plot (figure 4.5) is the raw sEMG signal called the time-domain representation (in red) and the second plot (figure 4.6) is the frequency-domain representation (in blue), both plots show the entire test duration, approximately 275 seconds.

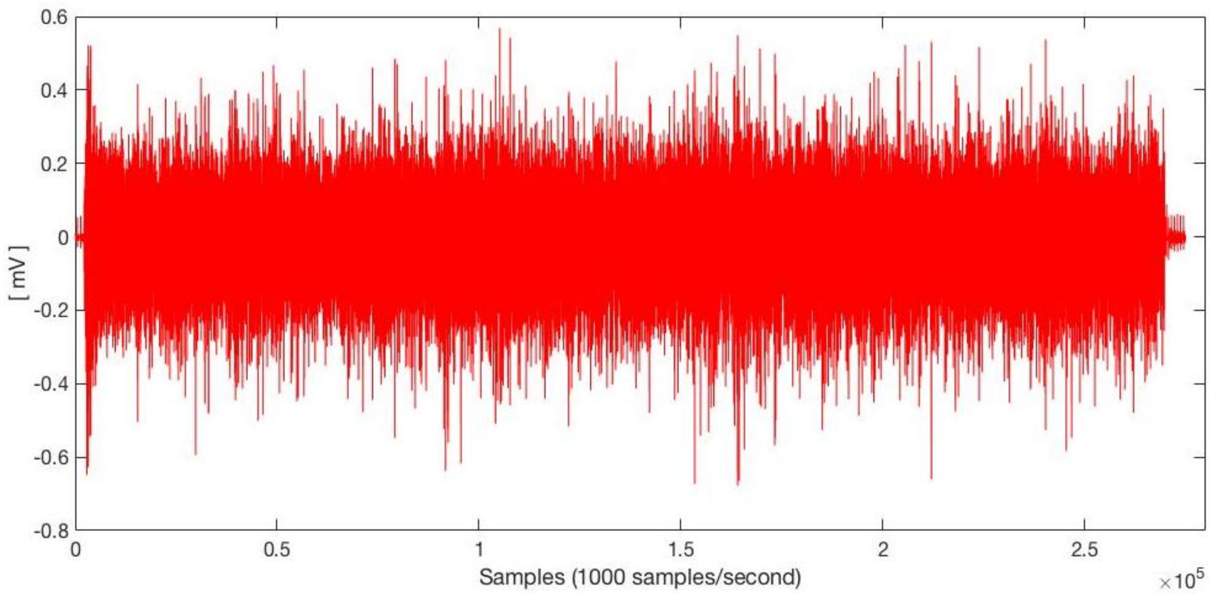

Figure 4.5: Plot of the raw sEMG signal called the time-domain representation.

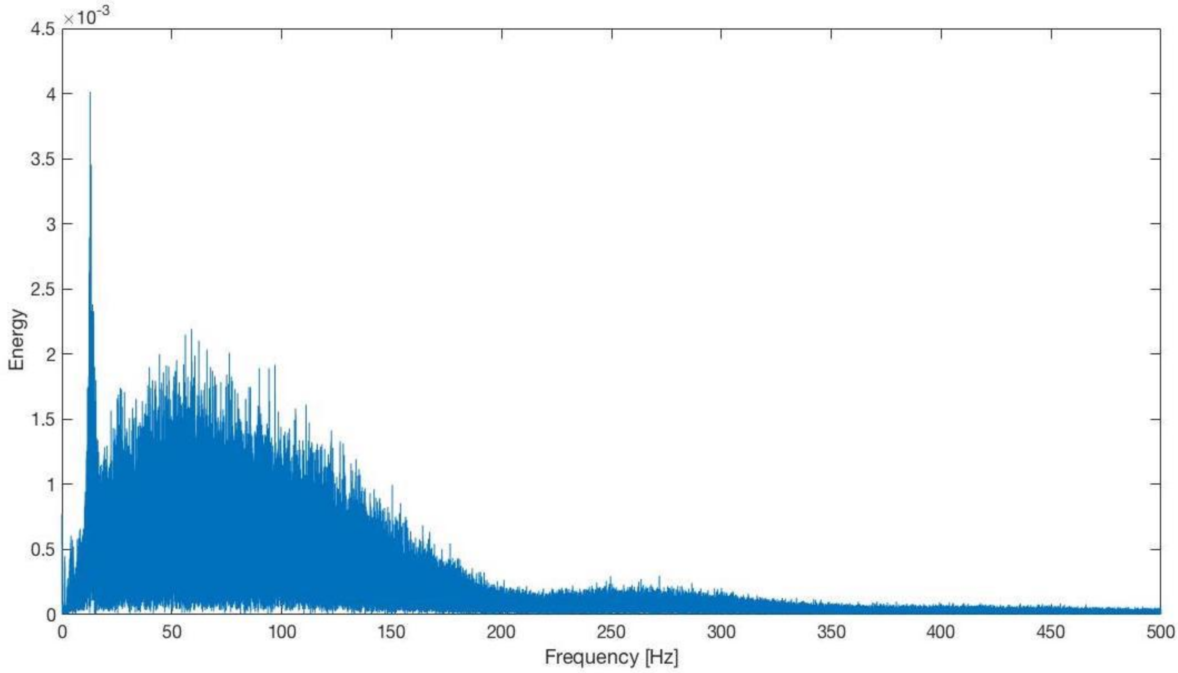

Figure 4.6: plot of the frequency-domain representation.

The plot below in figure 4.7 displays the data when it is observed for one second in the frequency-domain (Time: 10'th second - 11'th second). Frequencies below 5 Hz are eliminated due to very high values (spikes) which are of no interest because they do not derive from muscle contractions.

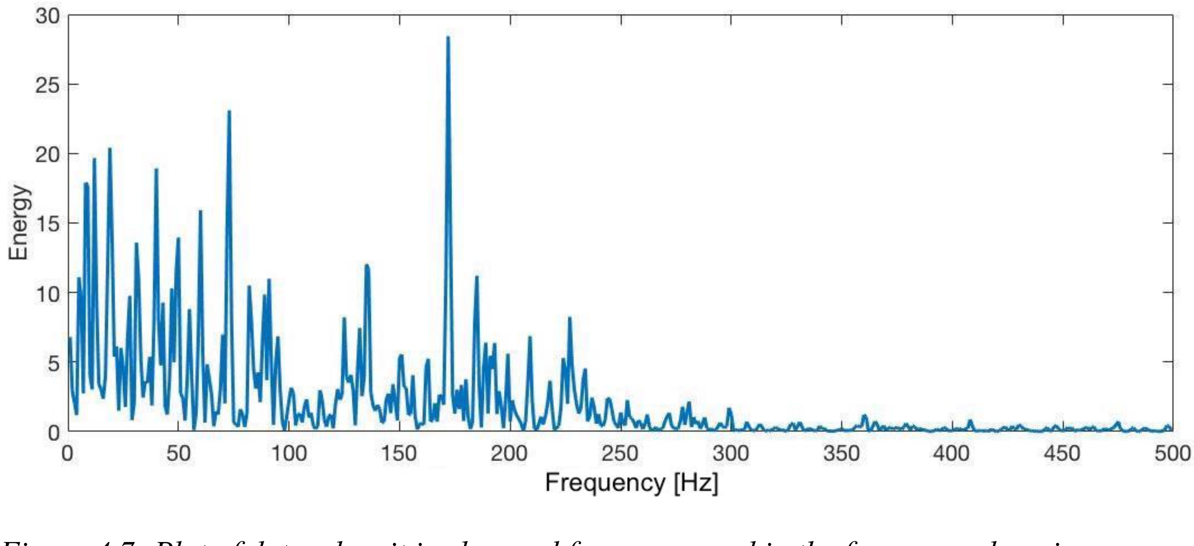

Figure 4.7: Plot of data when it is observed for one second in the frequency-domain.

What can be seen in the plot below in figure 4.8 are "spikes" of energy in the signal at certain frequencies which may come from noise and this affects the MDF and MNF calculation in the way that no clear frequency shift can be seen. This problem was solved by adding bandwidths into bands with their respective energy values. A plot below displays this with a frequency bandwidth of 10. This means for example that frequencies 5 Hz up to 15 Hz are summed into one band with their respective energy values.

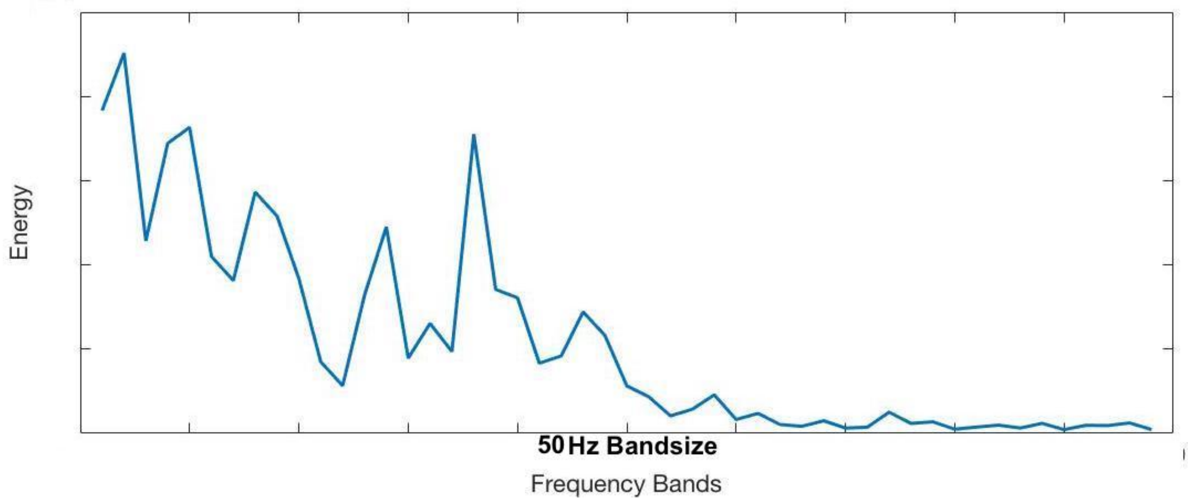

Figure 4.8: Plot that illustrates "spikes" of energy in the signal at certain frequencies.

Several ways of filtration were done in order to observe the desired results. First was to adjust the width of the bands in order to average out energy spikes and with the last static test in the project it was found to work well with a width of 50 (so for example 100 Hz up to 150 Hz were summed into one band). The second way to filter the signal was to remove frequencies below 5 Hz due to large noise spikes below 5 Hz. The third and last filtration was done by observing the data from the 4'th second (just as soon as the arm was lifted) up to the 200'th second. The reason not to observe the last 75 seconds was because the subject slightly adjusted the posture of the arm due to fatigue, and it was considered that other muscle units would then have been recruited in the muscles and affected the results. A 3D plot is displayed in figure 4.9 below, where the x-axis is the time duration, the y-axis shows the frequency bands and the z-axis shows the energy content in each band. The 3D plot shows a power increase in the lower frequencies as time increases, which in a way shows an MDF and MNF decrease but also an amplitude increase which is what was the desired outcome and confirms the De Luca theory. This meant that fatigue could be measured by processing the sEMG signal, and this was used in the product concept later to observe fatigue progression. The code for the 3D plot is found in appendix I.

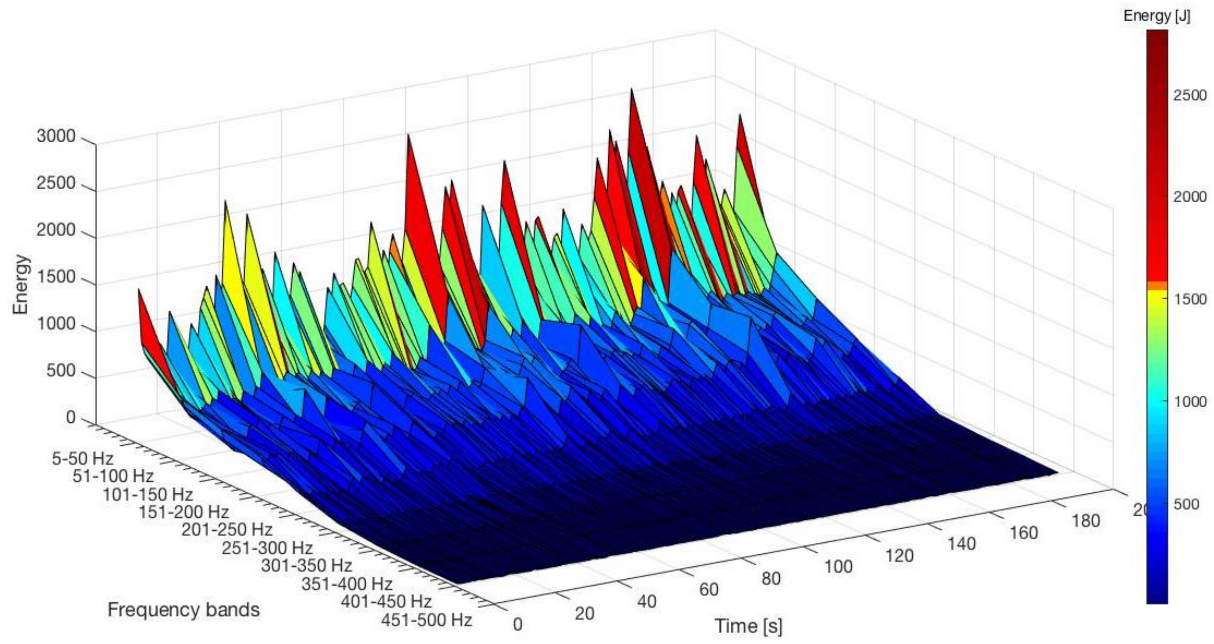

Figure 4.9: Plot of the energy content in each band.

This filtering solution is what the authors propose should be utilised in the fatigue analysis in the product concept. The proposed concept signal processing works by having the user lift their arm in the same way as was done in the last static test (seated and lifting the arm up to 90 degrees) to allow the product to collect the sEMG data in order to see the progression of fatigue over time. The interval of how often users need to do this exercise needs to be further evaluated, but as the customer questionnaire showed, many would allow this to be done every 4h. The more times they would do this exercise, the higher resolution there would be in the data, and more accurate assumptions could be made.

By following the fatigue progression and collecting information about the muscle health status from many users over a long period of time (months/years), the authors argue this could result in correlating threshold levels in muscle fatigue to when muscle injury occurs in a combination of continuous monitoring of the muscle activity. This proposition is based on the Cinderella Hypothesis which was explained in the beginning of this paper. Basically, the idea of the hypothesis is that if a muscle is not given enough time to recover then injuries will occur, and by avoiding a high fatigue level and high muscle activity level over a long time, this can be avoided. By mapping when muscle injuries occur in the long period data collection, with regards to fatigue level, the product can be fine-tuned to alarm the user of when rest is necessary to avoid injury.

4.4 Concepts

Twelve concepts considered to be realistic and had potential were generated. These concepts were divided into three groups in order to ease the handling of them, the groups were based on the way the electrodes were fastened to the user's body.

The three groups were the following:

Patch: The EMG electrodes are fastened to the user's body by being attached to a glued patch.

Compression clothing: The EMG electrodes are attached or sewn onto compression clothing, similar to those used when working out. The benefit of compression clothing is that they are tight and therefore the electrodes will have good contact with user's skin while also not limiting the user's movements.

Others: This category covers all the remaining concepts that did not fit into the other categories and that did not have a large number of concepts in order to have their own category.

4.4.1 Patch concepts

The first two concepts (illustrated in figure 4.10) both consist of large patches with glue that should be fastened to the back of the user. The Patches have predefined points for the position of the EMG electrodes and a structure where the signal receiver and sender part can be fastened. The signal receiver/sender part is a small plastic shell with all the technology needed to handle the signals. However, the computing is done externally. The first concept sends the computing to an application on the user's phone or on a PC, while the second concept utilises a smart-wristband to compute and inform the user. So the information is displayed to the user either in their mobile, a nearby computer or on the smart-wristband with supported applications. Alarming the user is achieved by emitting sound or vibration from the devices.

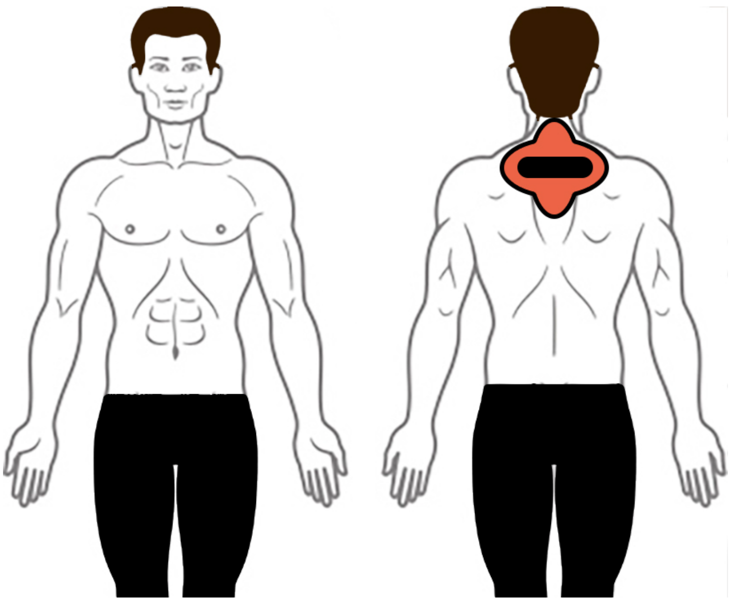

Figure 4.10: illustration of the patch for the first two patch concepts.

The other two concepts within this category are also quite similar to each other. They consist of plastic pucks and contain the technology required for sending the sEMG signal to a computational unit. Each puck handles a pair of electrodes and both the puck and the electrodes are fastened to the user's skin by using patches with glue. The computational unit could be a smart-wristband that can visual the information as well as warn the user if the muscle activity level is harmful, this is done by vibration and led lights. The difference between the two concepts is that one has a big tape patch with the electrodes fastened to the sender/receiver puck (see picture to the right in figure 4.11), while the other one has all parts separately and they are connected with wires to the puck (see picture to the left in figure 4.11). The product with the big tape patch therefore becomes easier to fasten for the user as the tape has everything correctly placed, while if using the second version of the concept, the user has to attach the electrodes with the correct distance between them.

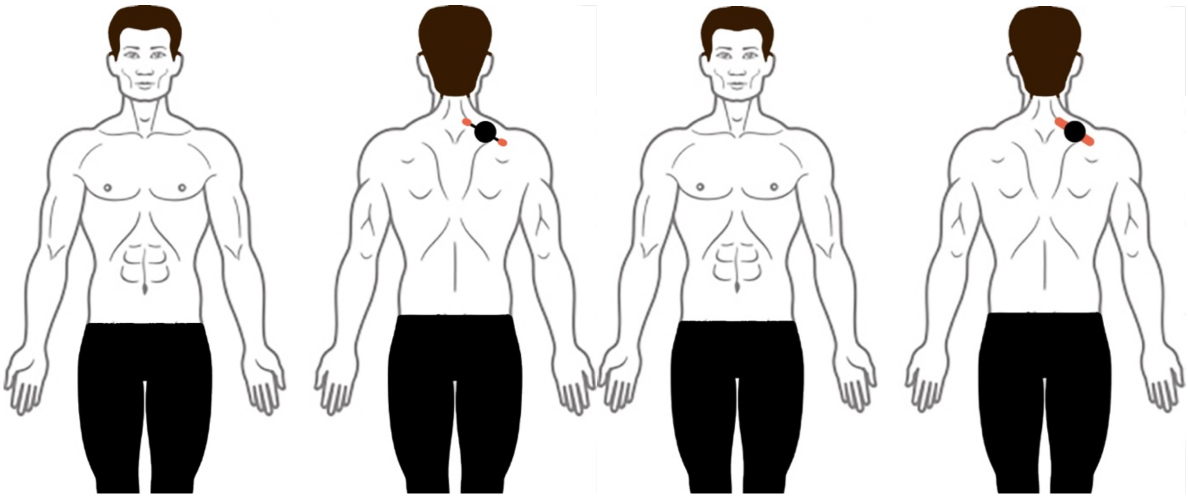

Figure 4.11: The left picture shows the sender/receiver with wires and small patches, the right picture shows the sender/receiver with the big patch.

4.4.2 Compression clothing concepts

The first concept presented (illustrated in figure 4.12) within this category is a long sleeve compression shirt with EMG electrodes without either glue or gel attached to it. A small signal handling plastic puck with internal computing is attached to the shirt, calculating and sending the captured information to a colour display that is attached to the arm of the clothing that shows the information graphically.

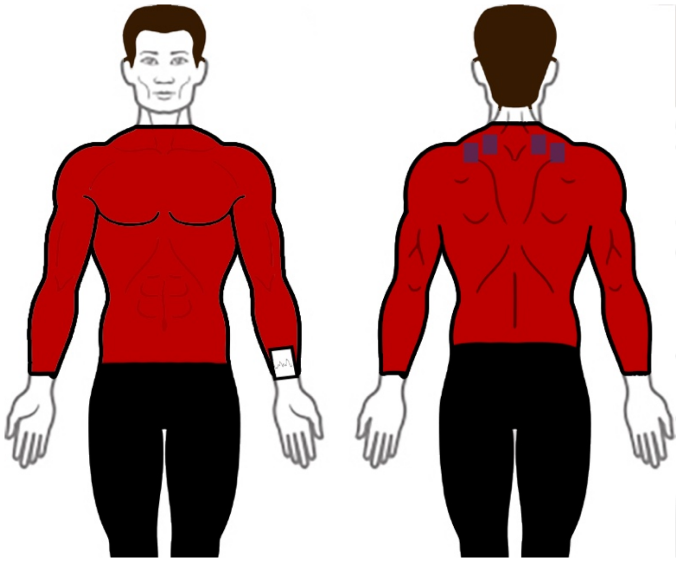

Figure 4.12: Illustrates the first compression clothing concept.

The next concept within this category was inspired by protection gear used in sports (illustrated in figure 4.13), such as shoulder and knee protection used when playing handball. The product consists of a piece of compression textile with electrodes without glue or gel attached to it. This makes the product modular as each part only monitors one part of the body, so if the user wants to monitor their shoulder activity, they should use the product for the shoulder. A plastic shell that contains all of the technology for handling signals and computing is attached to each of the garments. The shell sends the information to a smart-wristband that visuals the information to the user as well as warns the user if needed.

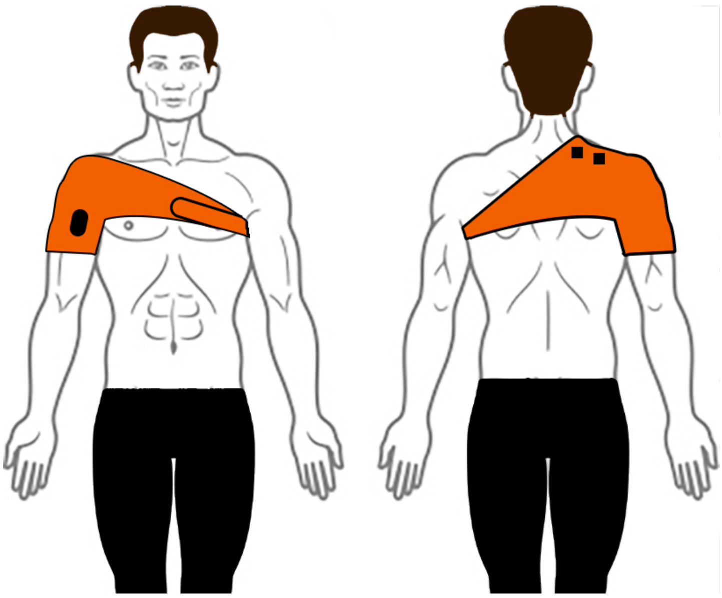

Figure 4.13: Concept illustration of the concept inspired by protection gear.

The two remaining concepts in this category are very similar, as the second one is just a variation of the first one. The concepts consist of a long-sleeve compression shirt with electrodes without gel or glue, sewn and attached into the fabric. Regarding the first version of the concept, it had one rubberised puck that handled signals connected at every pair of electrodes (illustrated in figure 4.14). Each and every one of the rubberised pucks send the collected signal to a mobile device that has an application installed on it. The mobile device calculates the data and visuals the information to the user. The application can also warn the user through using sound and vibration. The second version of this concept has only one rubberised puck connected to all of the electrodes. The second version also has a smart-wristband that can visualise the information and warn the user.

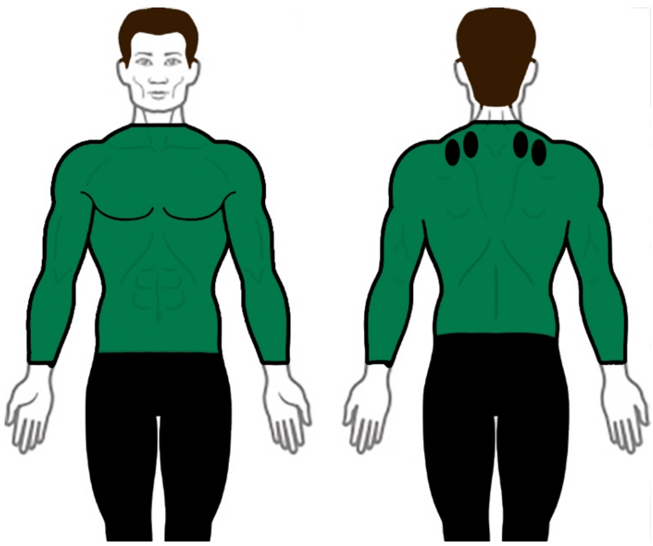

Figure 4.14: Illustration of the concept with one rubberised puck that handled signals connected at every pair of electrodes.

4.4.3 Other concepts

One of the concepts that did not have its own category was a concept that consisted of long sleeve shirt where the textile was smart textile, which can be seen in figure 4.15. However, since smart textiles were not being considered at this time, it will not be described other than that it was very similar to the compression shirt but used smart textiles instead of compression shirt textile.

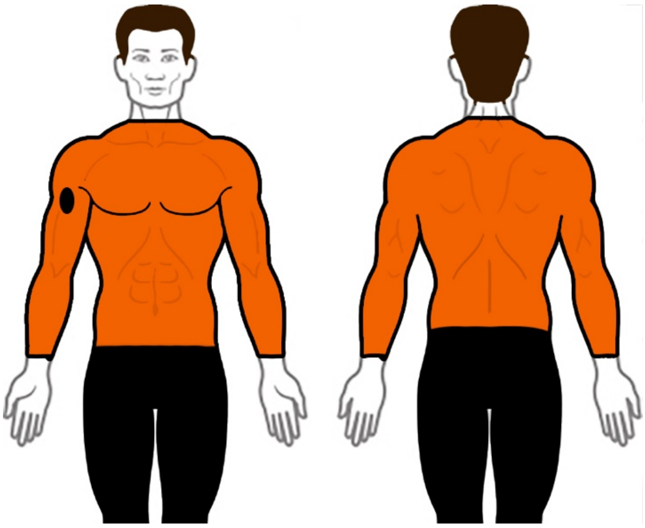

Figure 4.15: The smart textile concept.

The next concept to be presented was called the back plate as the concept has a big patch without glue that is placed on the back of the user. The back plate is held into place by backpack inspired strap that can be tightened (illustrated in figure 4.16). The patch had EMG electrodes without glue attached to it, also attached to the patch is the handling signals part that is capsuled in a plastic shell. This part sends the captured information to an application on the mobile device that user has. The app does the computing and visualises the information to the user via the phone.

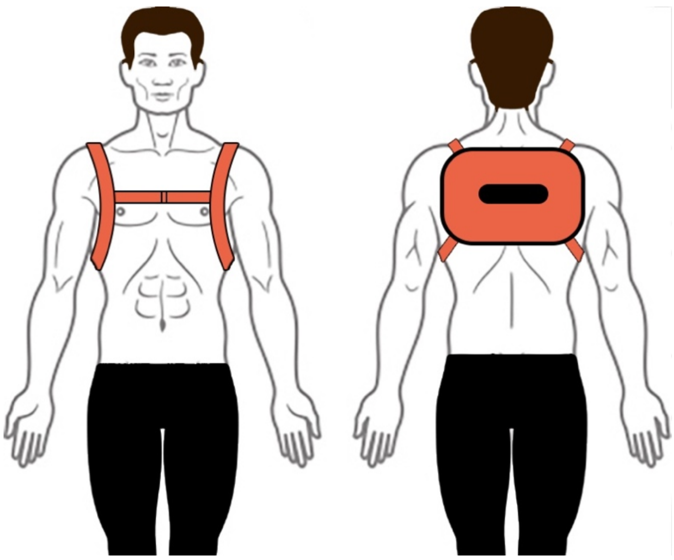

Figure 4.16: Illustration of the backplate with a strap that can be tightened

The following concept used a different approach when it came to wearable clothing. Instead of using compression shirts as the majority of the other wearable solutions it uses a matrix or web of electrodes attached to a t-shirt or a tank top (can be seen in figure 4.17). The information is sent to a mobile application that does the computing via the receiver and sender part attached to the matrix. The application then shows the information to the user and can warn the users if the muscle activity levels are on a harmful level.

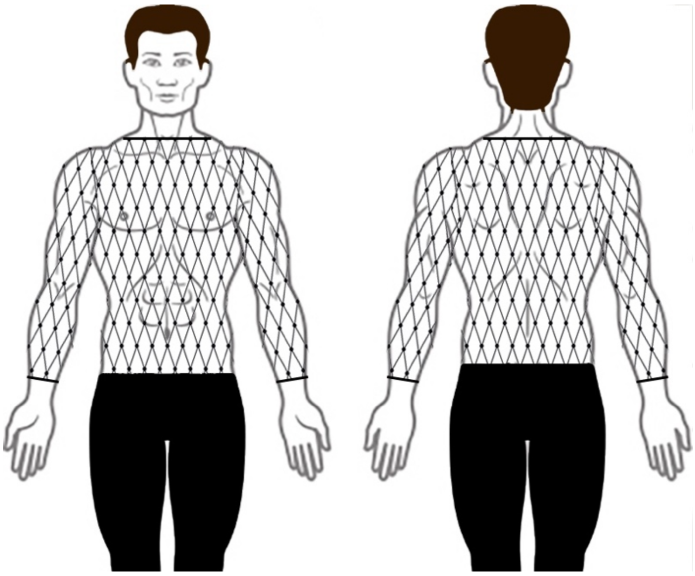

Figure 4.17: concept picture of the "net-shirt".

The last concept to be presented consists of stretch clothing that contains a matrix of electrodes. On the back of the shirt, a big thin plate made out of rubberised plastic (that is inspired by the safety backplates used in extreme sports) that contains all of the technology needed for both handling signals and for all computing. The idea of having such a big cover for the technology part is that it then could be modularised and more parts could be added further on. The information is then sent and shown on the user phone via an application. In figure 4.18 below a picture of the can be seen.

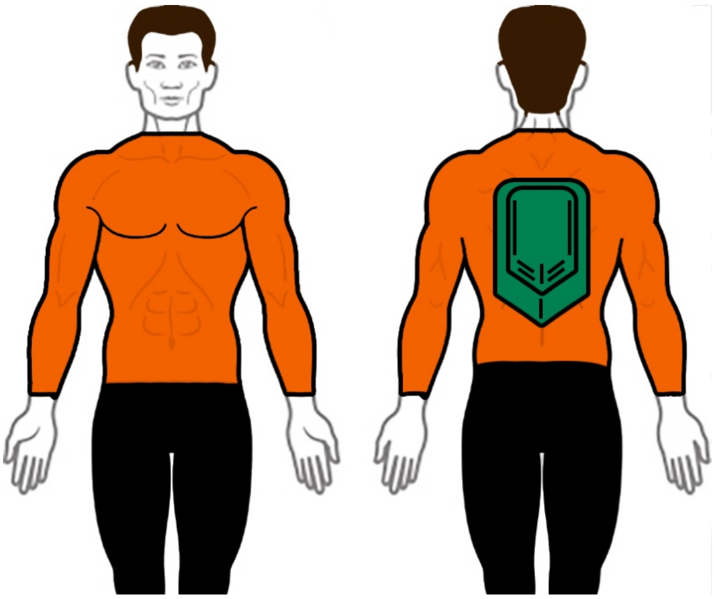

Figure 4.18: The extreme sports inspired concept.

4.5 Concept elimination

After the concepts had been generated they were placed in an elimination matrix (appendix D), how the elimination matrix works is described in chapter 3.5.2. Six criterions were set, namely, does it solve the main problem, does it fulfil all demands, feasibility, reasonable cost, safe and finally, is there enough information. Four concepts were killed at this stage. The first concept to be killed was the smart textile concept since smart textiles were not to be considered in the project but also it was not feasible as smart textile are yet to be developed to the necessary level. Furthermore, the concept would also be expensive and more information was needed. The second concept to be killed was the protection gear as it did not fulfil all demands. The protection gear was also thought to be expensive both to develop and buy if the product would be made for multiple muscles, this since the product then would consist of e.g. two shoulder protections and two elbow protections and so on. The third prototype to be killed was the net shirt as it was evaluated to be expensive and there was a large knowledge gap as it was unclear if it did fulfil all demands and if it was feasible. The extreme sports backplate was the final concept to be killed at this stage as it did not meet all of the demands and would be costly since it would have great computing power.

In the Pugh matrix which was the next step of the elimination four more concepts were killed, how the Pugh matrix works is also described in chapter 3.5.2. This was done after two iterations of the Pugh matrix with different reference concepts. The concepts killed were the puck with patch concepts and the concepts with large patches on the back. The four concepts killed got a score of minus six on both of the iterations. A score of minus six was believed in both of the scores was evaluated to be far too bad to take the concepts further. The reasons for the score was similar for all of the concepts as they were evaluated to be worse than the reference concepts in mainly the same criterions, those criterions are found in table 4.3 below (all criterions of the Pugh matrix are found in table 4.2). The criterions that differed between concepts that were killed were 'Intuitive to use' and 'modularity' in both iterations. The puck with patch concepts were the concepts that were evaluated to be less intuitive to use while the concepts with large patches on the back were evaluated to be less modular. To see the full results from the Pugh matrix, see appendix E.

Table 4.2: Criterions for the Pugh matrix.

Criterions
Transmit result from sensors to monitor
Function with low amount of gel
Complies with concept specific IP67 class requirements
Comfortable to use
Time to install
Fastening removal time
Shock resistance
Design prevents user from harming themselves (wristbands are harmful)
Ease locating the correct position
Intuitive to use
Reusable
Washable/cleanable
Replaceable parts to enable further income during product lifecycle
Provide hassle free link
Visual feedback
Modularity

Table 4.3: Criterions with a worse score than the reference concept that were the same for the killed concepts in both iterations.

Function with low amount of gel
Complies with concept specific IP67 class requirements
Comfortable to use
Time to install
Fastening removal time
Ease locating the correct position

Four concepts remained and were evaluated further in a final step, namely the Kesselring matrix, the way the Kesselring matrix works is described in chapter 3.5.2. After giving the different concepts their score for each criterion and then multiplying it with the corresponding weight a result was reached, the criterions and their weight are found in table 4.4. The Compression shirt with a screen on the arm and the compression shirt with one single sender/receiver puck got the highest scores, they got 273 respectively 269 out of the maximum score of 295. Since the score was so close it was decided that the final concept would be a combination of the two. To see the full results from the Kesselring matrix, see appendix F.

Table 4.4: Criterions of the Kesselring matrix with their weight. (w = weight, v = value, t = total score).

Criterions		**Ideal**	
Type	w	v	t
Transmit result from sensors to monitor	3	5	15
Function with low amount of gel	3	5	15
Complies with concept specific IP67 class requirements	4	5	20
Comfortable to use	5	5	25
Time to install	5	5	25
Fastening removal time	4	5	20
Shock resistance	4	5	20
Design prevents user from harming themselves (wristbands are harmful)	3	5	15
Ease locating the correct position	4	5	20
Intuitive to use	5	5	25
Reusable	3	5	15
Washable/cleanable	3	5	15
Replaceable parts to enable further income during product lifecycle	2	5	10
Provide hassle free link	4	5	20
Visual feedback	5	5	25
Modularity	2	5	10
Total		80	**295**
Ranking			**1**

4.6 Final concept

Figure 4.19: The MuscleGuard logotype.

The final product concept called the "MuscleGuard" (logotype displayed in figure 4.19 above and the product is displayed in figure 4.20 below) is a combination of the two concepts which survived the Kesselring matrix and it consists of a compression shirt with embedded sEMG electrodes. The electrodes utilise the same technology as previously discussed existing electrodes which are reusable and washable. The concept also has a wristband that displays and informs the user about their muscle activity. The display of the wristband can be detached and instead mounted on a belt or on the specially designed strap on the arm of the compression shirt. Below each part of the product is described more in detail.

Figure 4.20: Picture of the final prototype.

4.6.1 The compression shirt

Figure 4.21: Image of the compression shirt used in the product.

As one of the most important goals with the product was to have a comfortable product, wearable technology fit the criteria greatly. Compression shirts are used when working out since they have a positive impact on the body including the muscles. Compression clothing increases the pressure in the veins which leads to the blood faster returning to the heart and lymph nodes. This in its turn gives faster and better circulation which faster warms up the muscles. The increased pressure also decreases the risk of thrombus and swollen feet and legs for instance. One of the reasons for why the muscles get tired when working out is that they get exposed to impact and vibration. Compression clothing reduces this by giving extra support to the muscles and also increases the blood flow which gives faster oxygen supply to the muscles, this decreases the muscle fatigue. Reducing the impact and vibration can also reduce muscle fibre injuries. As mentioned earlier in the report, the compression shirt (seen in figure 4.21) has non-adhesive surface EMG electrodes embedded to it, they are placed in the areas of the most commonly injured muscles, such as the trapezius muscle. The electrodes are connected with wiring in the shirt to a connection point for the part of the product that collects all the data. The electrodes are proposed to consist of similar technology as the found existing electrode patent/existing product but will require a further evaluation of how well they are suited for this application. The connection point is placed on the bottom right side of the compression shirt and the puck can easily and be slid into place in and secured order to collect the data. As the compression shirt sits tight on the body it secures a good contact between the embedded sEMG electrodes and the user's body and that are placed in the correct place all the time. Another positive thing with having a compression shirt is that the regular work clothes can be worn on top of it. The shirt has a specially designed strap on the upper arm where the display casing can be attached on. The electrodes are machine washable as delicate fabrics. Finally, the compression shirt should be available in as short-sleeve as well, since it is forbidden to have long sleeve shirts within most of the healthcare sector.

4.6.2 The puck

This is the part of the product that collects the data recorded by the EMG sensors embedded in the compression shirt. The collected data is then sent to the user's wristband and/or mobile application via Bluetooth where it is calculated and displayed. They then calculate muscle fatigue, muscle activity as well as the muscles active and resting time. The puck is placed on the compression shirt through being attached to the attachment point stitched onto the compression shirt (figure 4.23 shows the puck and attachment point). This done by removing the removable top part (#1 in figure 4.22) of the attachment point and then sliding the puck onto the attachment point thru the connection rails (#2 in figure 4.22) and closing the attachment point again with the removable top part (#3 in figure 4.22). Since the final product should have an IP67 standard, the puck is dust and water resistant so it can be used in a large variety of working environments. The puck has a target battery life of 10 hours and can easily be charged by just putting it on the charger plate that charges it via induction.

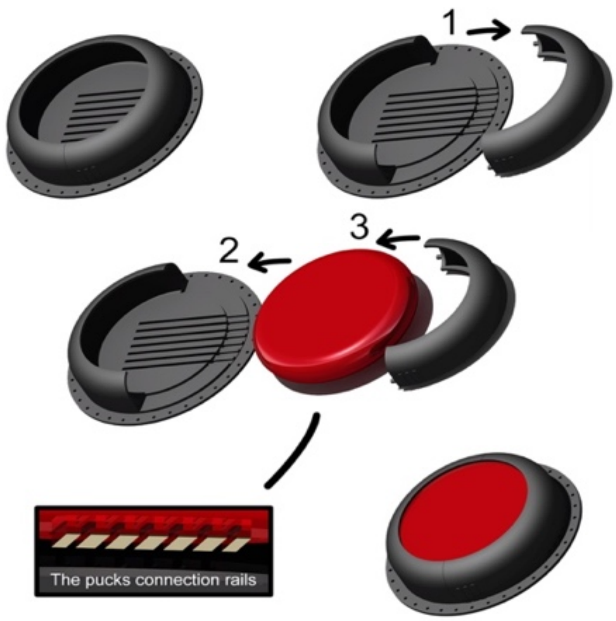

Figure 4.22: Image illustrating how to attach the puck to the compression shirt.

Figure 4.23: Image of the puck in attached to the attachment point.

4.6.3 The wristband

Figure 4.24: Image of the wristband.

If someone might not have access to their cell phone during the working day, it has been essential and important to develop a supplementary product (shown in figure 4.24) that can be used to display information to the user throughout the working day without being in the way. The wristband case consists of a 1,9 inch (48mm in diameter) colour touchscreen with a small notification speaker. It also has two buttons (shown in figure 4.26) on the side that makes it possible for the user to fast and easy can set the volume of the wristband. On the back of the case a clip is found, which in its original position is closed thanks to springs used. The clip can be used in two different ways, the first way is that by closing the clip after placing a wristband on to its place, the case will be securely fastened to the wristband. The wristband can only be placed in one way because of the shape of the wristband and the casing that has an attachment point underneath the clip. The second way to use the clip is to place the lid between the compression shirt and the strap on the shirts arm or on a belt. It will then be fastened on the arm or a belt instead of on the user's wrist if it would not be accepted to have wristbands while working. This is the key reason to why the display is detachable from the wristband, as many workplaces prohibit workers from having wristbands as they might be the cause of serious injuries. If workers for instance load machines with material, then there is a risk of entanglement with a wristband which could lead to serious injury or death. By offering a solution which can be placed on the shoulder, this risk can be drastically reduced. The wristband is available in different colours which are shown in picture 4.25 below.

Figure 4.25: The wristband in different colours.

The wristband displays necessary information to the user, such as muscle fatigue level. It does also warn the user with sound and vibration. The sound can be turned off not to disturb the user's surroundings and therefore the vibrating alarm is needed as well. The information that is analysed and displayed is information received wirelessly through Bluetooth from the puck. To shift between the different screens, the user only needs to swipe the screen to the left or right. The wristbands target battery life is of up to 24 hours and does also charge through using the induction charging plate.

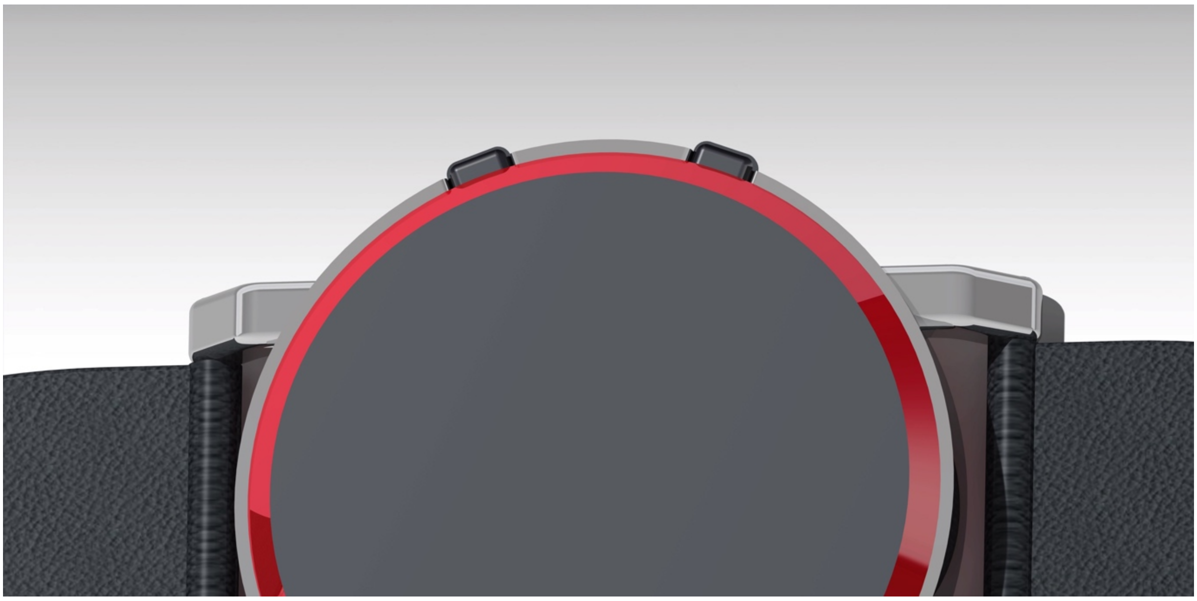

Figure 4.26: The two black volume buttons of the wristband are can be seen at the top of the image.

The wristband has five different screens that the user can swipe between (Reference movement screen explained further down is not available at all times) which can be displayed. They show different information and are described below.

The home screen:

The screen (illustrated in figure 4.27) that serves as a home screen for the wristband is like a regular watch, as it shows date and time. It is also this screen that indicates the wristbands battery level.

Figure 4.27: Illustration of the home screen.

Fatigue level:

This screen (illustrated in figure 4.28) displays the overall muscle fatigue level of the activated muscles. It can also show the muscle fatigue level for each muscle if the user taps on the screen, which would also lead them to the name of that muscle. The muscle fatigue level is presented in percentage on the screen as well as with a graphical gauge, in order to keep it as easily understandable as possible. This screen also recommends the user when to take a rest based on the muscle fatigue level.

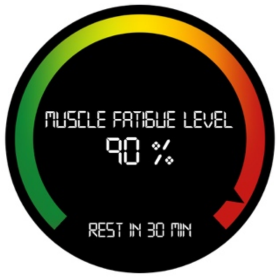

Figure 4.28: Illustration of the muscle fatigue level screen.

Fatigued muscles:

This screen that can be seen in figure 4.29 visual informs the user which muscles that are fatigued. If the muscles are not filled with any colour (black) it means that the muscle is not fatigued. Should the muscle be filled with yellow colour, it means that the muscle is on its way to becoming fatigued. Finally, if the muscle instead is filled with red colour, this indicates the muscle is fatigued.

Figure 4.29: Illustration of the fatigued muscles screen.

Questions:

This screen is a key contributor to the functionality of the proposed solution. In order for the product to be able to predict injuries in the future, questions about the user's health needs to be gathered. By collecting the user's muscular health (the questions on the display) on a large scale, and correlating that information with the user's sEMG fatigue and activity analysis, the authors argue this will result in a statistically valid injury prediction method. Questions displayed here are for explanatory reasons need further development in order to extract the necessary user information. An illustration of the questions screen can be seen in figure 4.30.

Figure 4.30: Illustration of the questions screen.

Warning:

The last screen that can be seen in figure 4.31 warns the user if needed. The screen will automatically pop up and the system warns the user with sound and vibration the user, so there is no need to keep on swiping to get updated. If the user swipes to the screen it will see a log of the earlier warnings, so no information is lost.

Figure 4.31: Illustration of the warning screen.

4.6.4 The phone application

If the user rather wants to use his or her mobile phone a mobile application (figure 4.32) can be downloaded from where applications are found. The mobile applications do perform the same analyses and calculations as well as displays the same information as the wristband and does also warn the user if needed with sound and vibration. This means that it has the same screens as the application for the wristband but they are optimised for a larger screen. The user still just swipes left or right to switch between the different screens. The application also has a screen where reading tips and information about work-related musculoskeletal disorders are linked. The app can also send notifications if the app is running in the background. The application is easy to connect to the puck via Bluetooth. By allowing customers to only use their mobile phones, then the product without the wristband can be sold at a lower cost, attracting other market segments.

Figure 4.32: Illustration of the mobile application.

4.6.5 How the product works

The proposed concept is a complex product and might be challenging to understand, so here follows an explanation of how the product works. The embedded EMG electrodes in the compression shirt capture the muscular electric activity, this is sent to the sender/receiver puck through the embedded wirings. The puck collects data and sends it to the application for the wristband or mobile application. The application then analyses and calculates the data with the built-in script and shows the result in real-time. The two ways the product will analyse the muscles is by checking fatigue level and how much activity the muscle has had throughout a period.

Before the product can notify of harmful fatigue and activity levels, the system needs to "learn" by collecting user fatigue level (with the static exercise) and the continuous activity collection together with their health reports (which is filled-in on the display in the "questions" menu). When a statistically valid amount of people has worn the product, while also had muscle injuries and reported these (reported in the product display "questions" menu), then the right fatigue threshold level and the right activity threshold level can be set in order to avoid muscle injury by notifying the user to rest.

As the puck will collect data throughout the day, it will analyse if a muscle is activated for a long period of time by looking at the muscle activity from the EMG signal. If the muscle has been activated a significant period of time the wristband or mobile application will warn the user and recommend him or her to rest soon.

4.6.6 How to use the product

The following subchapter describes how the product should be used. The user begins by putting on the compression shirt. It is important that the users do choose the right size of clothing as it has to sit tight on the body so that the electrodes get a good connection to skin, therefore a size chart should be available.

The user then picks up the puck from the charger table that is illustrated in figure 4.33. The next step is to connect the puck to the compression shirt and activate it (as was explained above). This is first done by removing the top part of the attachment point and sliding the puck into place and finally closing the attachment point with the top part (see figure 4.24). The puck starts automatically and wakes up when slid into position.

Figure 4.33: Charger plate with the products docked.

The user then picks up the information display from the charger plate and places it in one of three alternative ways. The first option (illustrated in figure 4.34) is to lift the clip on the back of the screen and attach the wristband strap to the wristband screen and closes the clip. The user then attaches the wristband on his or her wrist. The second alternative is to lift the clip and attach it to the strap on the arm of the compression shirt. The final option is to lift the clip and attach the information display to a belt. If the user instead wants to use his or her mobile phone they can skip this step.

Figure 4.34: Image of how to attach the screen to the wristband.

It is critical for the functioning of the product that the user answers the questions stated on the question screen. If the information display is attached to a belt, it might be easier to answer the questions before attaching it to the belt. By pressing and holding both buttons on the side of the information display for five seconds a new recording will start, if using the phone application, just press start on the home screen. A screen which displays the reference static exercise will then pop up and inform the user how to carry out this posture with an animation and sound. When the exercise has been performed, the user can start performing his or her working tasks. When the work day is over the user only has to remove the puck from the attachment point and the recording will be stopped. The user then places the puck and the information screen on the charger plate so it will be charged for the next use, finally if needed the compression shirt can be washed as delicate fabrics and then hang to dry.

4.7 Final technical specification

In the following sub-chapter requirements for the different parts of the product are stated. The requirements are the backbone of a functional and good product. The requirements specification for the product can be viewed in appendix C.

4.7.1 Electrode specifications

The electrodes might be the most crucial part of a working product, if the electrodes do not capture the signals correctly the data will be useless. The following requirements have therefore to be fulfilled in order to get data to a satisfactory level of accuracy. This has led to a number of requirements, the first one being that the bandwidth should be between 20-450 Hz, this in order to capture the majority of the relevant EMG activity. Since noise impacts the signal, the lower bandwidths will be cut off and the cut-off is set to 20 Hz. The amount of noise from skin to the sensor should be less than 2 μV.

Since the product should be used every workday it is important that is comfortable and easy to use, this sets requirements all the way to the electrodes. The electrodes need to be able to operate without having to clean the skin (sandpaper and cleaning with alcohol) or utilise gel, hence a requirement of a skin to electrode impedance equal or smaller than 10 KΩ. The electrodes should also be washable together with the compression shirt.

4.7.2 Puck specifications

The data receiver and sender in the product which is referred to as "the puck" collects the data captured by the electrodes and sends to the applications so that they can analyse and calculate the data. In order for the capture the bandwidths up to 450Hz the sampling rate has to be set to the double Hz, therefore. the sampling rate of the product is set to 1000 Hz. The typical raw EMG signal is between +/- 5000 microvolts according to the book: ABC of EMG, and the maximum tolerated noise set previously was 2 microvolts, therefore it is possible to calculate the necessary resolution of the A/D converter in order to detect the noise. The smallest increment a 16-bits A/D converter can detect is one part in 2^16=65 536, so 10 000 microvolts (+/- 5000 microvolts = 10000 microvolt span) divided by 65 536 = 0.15 mV, which is enough in this case. Therefore, a 16-bits A/D converter is recommended (Mccdaq.com, 2017).

A requirement set for the product earlier was that it should provide a hassle free link, this was translated into that it should be wireless with the exception for wires to the electrodes. This means that from the pucks attachment point wires run to the electrodes in the compression shirt and that the puck has to send the data wirelessly to the applications, this also means that it needs to be wireless powered. A requirement of a battery life of at least 10h is therefore set so that it lasts an entire workday. Since the puck should send the data to the applications, a requirement of a wireless range of 50 m with Bluetooth 4.0 is set for the sender, just in case if the wristband or phone is placed on a table while the user is working, making it possible to still receive the data.

Since the product should be used by people within a large variety of occupations, it was earlier decided at the initial requirements decided that it should have the IP code IP67 so it is dust and waterproof. Furthermore, the product needed to be shock resistant, in order to meet this requirement, the product needs to survive a drop from 1.5 m onto concrete. The height of

1.5 m is set since the puck will be placed on the bottom of the compression and the distance from the attachment point to the ground should, therefore, be less than 1.5 m.

4.7.3 Compression shirt specifications

The compression shirt is an important part of making a comfortable product and should be made with a stretchable fabric that comfortably contours the user's body, the fabric should also be breathable to avoid the user from sweating easily. As this shirt might not be recommended to wash as often as a regular shirt, the compression shirt should use “anti odour” technology, but when it is time for it to be washed it should be washable in a washing machine as delicate fabric. As mentioned earlier it is required that shirt is available both as a long sleeve shirt and a t-shirt so that people within healthcare can use the product.

4.7.4 Wristband specifications

The wristband should as the puck have a wireless range of 50m with Bluetooth 4.0. Since the wristband might be used as a watch before and after recordings, a battery life of at least 24h is set so that it can be used during an entire day without charging. The wristband needs to have a processor that has enough power to analyse and calculate the data and enough memory. A brief research showed that many smartwatches today use a Qualcomm snapdragon 400 processor or an ARM Cortex-M4 processor, so it is recommended to use one of them. The research also showed that a smartwatch has a memory capacity of at least 2GB, both of these requirements should be further investigated as the product is built.

5 DISCUSSION

In the following chapter, the project work is discussed. The discussion lifts questions such as whether the project aim was fulfilled or not, and if parts throughout the project could have been done in any other way. Some future recommendations are also stated at the end of the chapter.

5.1 Fulfilment of the project aim

The end result of the project was the groundwork required for the future development of a product. What was not achieved in the project was a final result which was able to predict muscle injury without further data collection and development. However, the authors argue this would be solved by utilising the developed concept to collect sEMG data continuously and the health status inputs in the application from a large number of users in real work environments to tune the alarming threshold for the users as a further development of the product. The authors believe this is needed in order to find statistically valid trends in fatigue and activity levels at which the muscles tend to get injured, and through these learn the system at which fatigue/activity levels thresholds the product should notify the users of potential muscle injuries. A large data collection for verification purpose was not feasible to achieve during the project due to time and resource limitations and was therefore left for i3tex to examine further.

Another part of the project which was handed over to the company to explore further was the component and material decisions for the concept. This decision was made early in the project by i3tex because the company had in-house expertise within biomedical engineering and component design. The authors wish to emphasise company's request which was to lay the groundwork of identifying customer needs and suitable muscle analysis methods for the prediction muscle injury and also an initial technical requirement for the product, which the authors believe was achieved.

5.2 Project Processes

The U. & E. m. was suited because of the novelty of this product development project and shaped the steps in the development process. The continuous planning, information collection, evaluation and documentation was inspired by the ACD^3 process and helped the understanding of the challenging area of biomedical engineering in this project. The authors believe that given an adequate amount of time in the project, the ACD^3 process would have been possible to fully commit to instead of combining it with U. & E. m. The authors argue that following all the iterative steps in the ACD^3 process, would have resulted in a higher level of detail in the final concept due to the iterative nature of the process and would have created a wider groundwork for the future development of the product for i3tex.

5.2.1 Information Collection

The continuous information collection consumed the largest amount of project time due to the wide knowledge gap. The authors argue that the gap could have been reduced faster if the information collection had been done more efficient, by for instance having a better communication with biomedical and sEMG experts. Having a better communication, in terms of asking more questions in order to clarify the goal challenges, might have resulted in a quicker identification of what areas to focus on in the project. This would have left more time for the development of the concept and collection of test data to verify the authors proposed solution.

5.2.2 Customer Needs & Requirements

The elicited customer needs & requirements were of great value for the development of the concept. The input received, mainly from experts and the questionnaire, shaped the end result of the project in terms of how the concept was designed, how the users wanted to control the product and the way the concept would fulfil its task of predicting and notifying the user.

What could have been done to fulfil the eliciting of customer needs in a more complete way, given enough time, was to create a mock-up of the winning concept in order to verify the ergonomics. By allowing users try the concept mock-up and collecting the user's feedback of the mock-up, an iteration of the customers' requirements could have been made and a more customer adapted concept would have been developed.

5.2.3 Testing

What could have been performed in a more efficient way was the testing part of the project. Due to the limited knowledge of sEMG measuring equipment there were a few errors during some of the different tests, which consumed significant amount of project time. For instance, the many settings in the software for the advanced measuring equipment created confusion and resulted in wrongful data acquisition in some initial tests, which needed to be redone. This could have been avoided if sEMG experts would have been consulted to share the knowledge of how sEMG equipment should have been operated, instead of only relying on manuals and instructional videos. The authors argue that this would have freed up more project time and might have resulted in a higher level of detail in the final concept, like for instance allowing the project members to identify possible manufacturing methods for the concept.

What was unexpected by the project members were the dynamic test results. Even though the tests were dynamic, and the De Luca theory states that static tests can only be utilised for the median frequency analysis, other authors have found that the frequency shift can be seen in dynamic tests as well. And it was surprising that the dynamic tests did not show any clear frequency shift (possibly due to signal noise). This led to a modification on how the product needs to be operated for it to be able to monitor fatigue progression and thereby notify of when possible muscle injuries could occur.

What could be a future challenge is if no clear trends are shown after a large data collection, which would render the concept useless from a user perspective. But the learning outcome would be of a value since this would indicate that other ways of solving the muscle injury prediction should be developed.

5.2.4 Concept Generation and Elimination

The concept generation and elimination process were less of a challenge than the authors initially thought. Reason being the valuable input from the customer questionnaire as well as the clear trend in "smart clothes" which indicated a good direction in the concept generation. A part of the concept generation and elimination process which should have been added if there had been enough time was an ergonomics verification step. There is a risk that the winning concept is difficult to operate when the display unit is fitted on the upper arm because the user needs to turn the head, and this might get uncomfortable. This would have been verified if mock-ups had been done in the project, but was left for the future development of the product.

5.3 Lessons learned

This project was a challenge for the authors due to several reasons such as time limitations, knowledge gap, resource restrictions and so on, and this led to a few recommended improvements for similar future projects.

The first improvement would be at the beginning of the project, in the literature stage. The authors struggled to identify a suitable direction in how the project goal would be reached, and this leads to an unsystematic literature study. This consumed a lot of valuable time and would have been achieved quicker if it had been sufficiently planned from the start.

The project was ambitious in its aim and this was noticed by the time and knowledge limitations. A more feasible goal would have resulted in a higher level of completion, instead of having to rely so profoundly on future development. Also, a risk with the end result was the uncertainty if it will actually work, which would have been reduced if a smaller task had been taken. For instance, evaluating the possibility to measure fatigue in dynamic movements might have been sufficient in itself.

Testing should have had a larger portion of the project time frame. The authors felt rushed performing the tests as they initially lacked experience in how EMG equipment should be operated. This led to retesting, project delays and frustration. The lesson learned from this was, even though manuals were available, a much more efficient way of learning advanced equipment would be to observe and ask questions to individuals who are well familiar with EMG equipment. This way would have clarified the significance of for example the impedance or the placement of electrodes more rapidly.

A part which would have improved the outcome for the project would have been to build a prototype or a mock-up. This would have created a higher quality for the end result in terms of how well the product fulfils customer demands. Their perceived thoughts and feelings are impossible to extract only with a questionnaire, and it is rather necessary to communicate face-to-face about a physical product in order to extract all of their perceived feelings about the product.

5.4 Future Recommendations

Because of the projects narrow time frame and limitations pressed by the maturity of the relevant technology, the authors wish to recommend the following future development:

5.4.1 Ergonomics evaluation

The winning concept needs an ergonomics evaluation which was not possible to perform during the project due to time limitations. All the different parts of the concept need to be scrutinised from an ergonomics point of view in order to end up with a user-friendly product, and this is highly recommended for the future development of the product.

5.4.2 Component design

The project did not cover the process of choosing right components for the concept as this would have exceeded the project time. This was discussed with the company i3tex and decided to be part of the future development of the product. A critical part of the further development of the concept will be to develop the washable and reusable electrodes, and in order to achieve this, i3tex can analyse the found electrode patent in order to achieve this. As discussed earlier in the report, these new electrodes also need to be evaluated how they get affected by body hair, fat and sweat.

5.4.3 Data collection

Future development is essential in order to make the product predict muscle injury. As mentioned in the Cinderella hypothesis chapter, large amounts of sEMG data needs to be collected in order to achieve statistically valid assumptions of at what levels of fatigue and muscle activity do muscle injuries occur. The concept is developed to collect this data with the fatigue and activity monitoring and the user health reports extracted from the questions in the display.

5.4.4 Expand the number of electrodes

The authors suggest that future development should lie in incorporating more electrodes at different parts of the body. This would increase the complexity of the product but might lead to a greater accuracy in the overall assessment of the musculoskeletal health. The proposed next step could be a concept which has upper and lower compression tights clothing with integrated electrodes. A suggestion of the electrode placements can be seen in figure 5.1 below, where the image to the left shows the electrode placement of the final concept in this project (only on the trapezius muscle) and the image to the right shows another future product with several more electrodes on the body. This would mean a whole new design for the existing concept as well as adding a lower part with a puck and compression tights to measure sEMG signal from the legs.

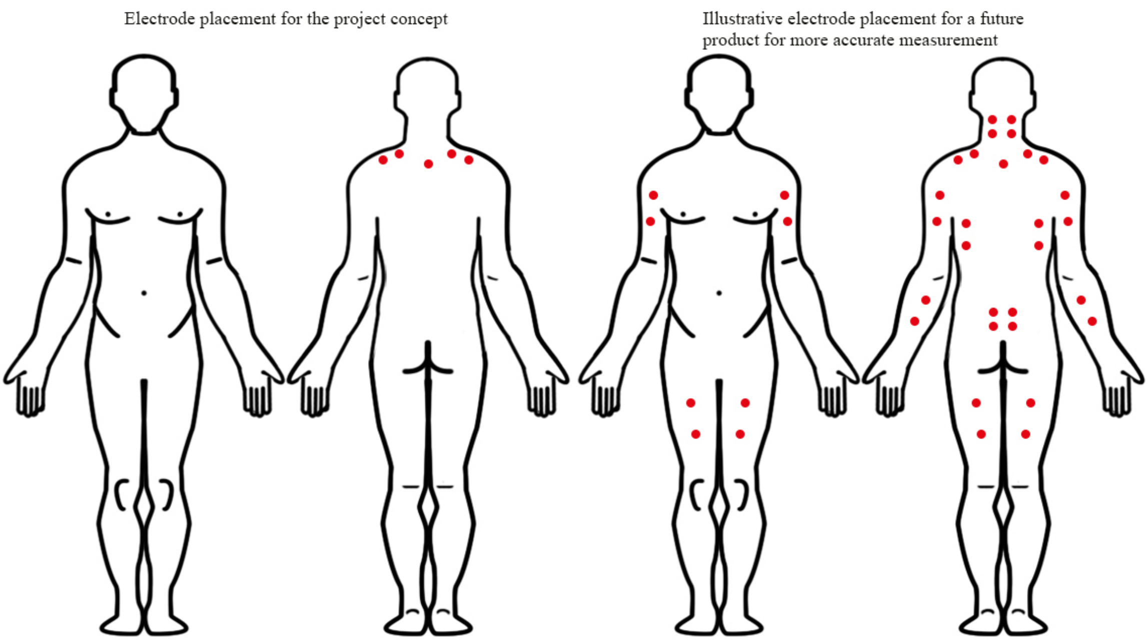

Figure 5.1: Image that illustrates placement of electrodes, (inspired and redrawn from the book: The ABC of EMG (Konrad, 2005, p.21)).

5.4.5 Adding gyroscope

By adding gyroscope in the future to the product it would become possible for the product to capture analyse the movements the user performs. Through this, the product can discover repetitive movements by the user and warn them when they have performed the same movements for a long time. In the future, it might be shown that EMG is not the ideal technology to use due to its sensitivity, and therefore gyroscopes might be able to replace EMG technology.

5.4.6 Material improvement

The product concept utilises a compression shirt to keep the electrodes in the correct place on the body, but this needs to be evaluated in order to ensure that body movement will not change the positioning of the electrodes in a way which will affect the analysis of the muscle status.

It is recommended that the company investigates the possibility of using smart textiles in the product in the future. This might make the product even thinner and more comfortable to wear while enabling a wider coverage of electrodes.

5.4.7 Reduce user inputs

Furthermore, it is also recommended to investigate the possibility of reducing or removing the reference movement in the future to simplify the use of the product. This could make the product more desirable and could be solved with the support of the collected data mentioned above in the data collection part.

6 Conclusions

This final chapter of the report aims at putting the major findings of the project into a larger context by reflecting on the purpose and aim of the project as well as what conclusions that can be drawn from the project.

This project a product for monitoring muscle activity in order to reduce work-related musculoskeletal injuries has been developed. The result is a concept product of a future product that can through a compression shirt with EMG sensors monitors the progression of muscle fatigue and muscle activity in real-time. The system notifies the user of when rest is needed to prevent muscle injury through sending a warning to the user's wristband or phone application. Knowledge gathered in this will act as support to further develop a product for the company.

The final design of the product aims at providing the users with different occupations a comfortable and user friendly way of monitoring their muscles throughout their working day. This has resulted in a comfortable compression shirt with embedded EMG non adhesive electrodes. The application is developed to be give clear and easy to grasp information through colour coded muscles and a gauge indicating muscle fatigue, but indicating when the user should take a rest.

Through conducting both a literature study and expert interviews important information was gathered that made it clear that a product collecting data over a long amount of time is needed. It also made of it clear the positioning of the electrodes is of great importance. Finally, it the results from the study and the interview stated that the trapezius muscle is the muscle to focus on to begin with. All of this together, led to a compression shirt being chosen for the product at it sits comfortable on the user but also sits tight on the body so the EMG electrodes have a good connection with the skin. Furthermore, the user does not have to place them correctly by them self, in order eliminate the risk of misplacement and making it quick and easy to wear.

The project concludes that harmful fatigue and activity levels can be identified, by initially utilizing the concept to collect statistically valid amount of muscle fatigue and activity data and correlating each user data with their own muscular injury reports to find trends at what levels injuries previously occurred. Furthermore, by monitoring the if a muscle has been active for a long period of time and recommend user to rest, monotonous and repetitive work with local loads and work related musculoskeletal disorders can be reduced.

If the company is to continue to develop the product the company has to look into if there are any possible medical standards that have to be met in order to launch the product, this was not taken into account during the project as medical standards is a jungle and it could have been a project in itself to see if a product like this one meets the standards. As for any other aid, a disclaimer of responsibility should be written that states that the user should seek medical advice if experiencing pain.

This product would be one of an its kind, this is a result of that no real competitors were found with the same purpose as this project. Instead they are focused towards sports technology and efficient exercise. The only product found that did not only focus on sports but also ergonomics instead used motion sensors and therefore it is not able to track muscle signals in order to analyse muscle activity and fatigue. Finally, this product fits the society of today, as we are entering a world of smart-devices and wearables.

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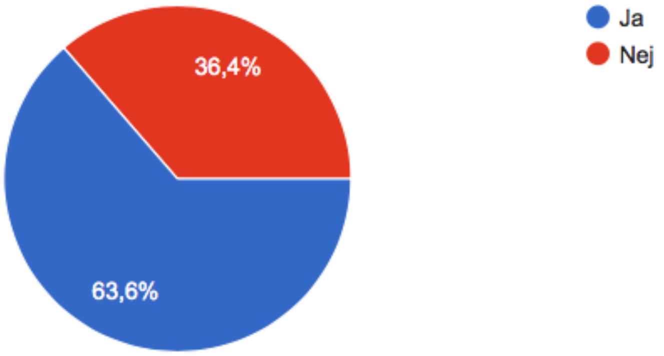
LIST OF APPENDICES

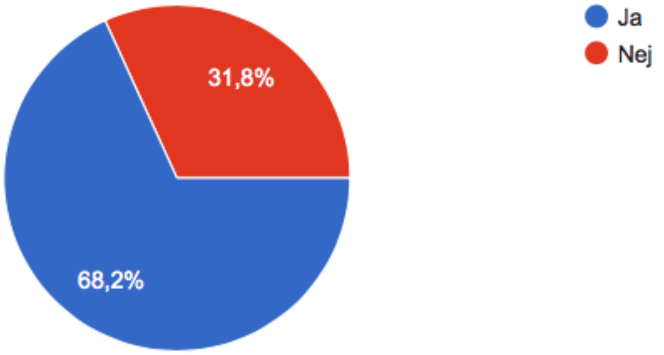
A - QUESTIONNAIRE

Sent to Swedish individuals and therefore was written and answered in Swedish, with 44 replies.

-I ditt arbete idag, känner du eller händer det att du känner dig fysiskt utarbetad/trött?



-Har du någon gång fått muskelvärk på grund av ditt arbete?



-Har du varit sjukskriven, varför i så fall?

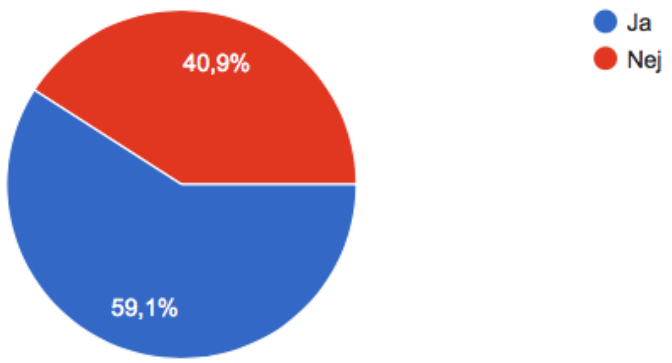
Pga muskelvärk
Förkylning
Ja bihålinflamation
Nej
Klämt handen i en garage port.
Infektion
Ont i armen.
Ryggbesvär
Bl.a. av balans mellan fritid och arbete
Muskelspäning
ja men aldrig på grund av fysiska skador utan psykologiska.

-Om du har haft muskelvärksproblem, hur ofta uppstår dessa problem?

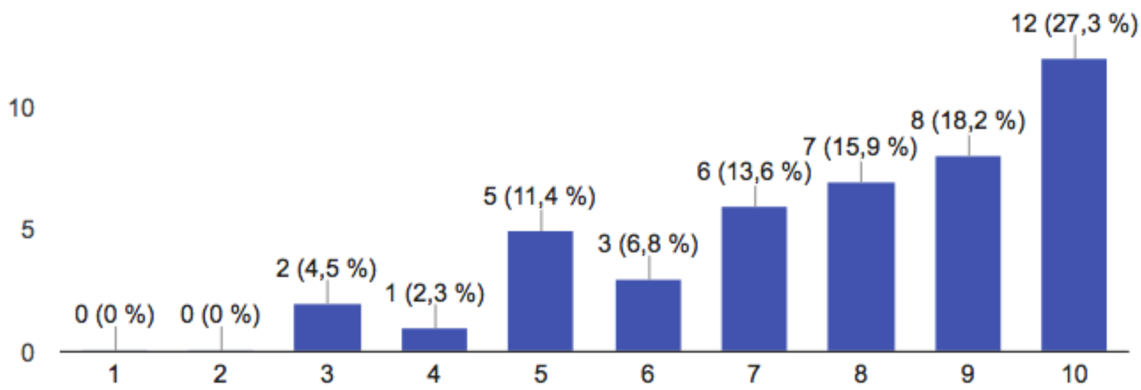
någon dag per månad
Varje månad
Någon gång per år
Ca 1gng i månaden
3-4 ggr per kvartal
1-2 ggr/år
I samband med att man mobiliserar tunga patienter i slutenvården.
Ja. I princip varje dag på arbetet
2-3gg/veckan eftersom jag gymma på arbetstid.
Någon gång i veckan
Varje månad
3 gånger per år

Dagligen
Någon gång i månaden
2-4 gånger om året.
Ibland
Någon gång i bland
Nej
Ont i rygg och axlar ibland
Ofta
en gång i månaden
varje dag
Dagligen på jobbet

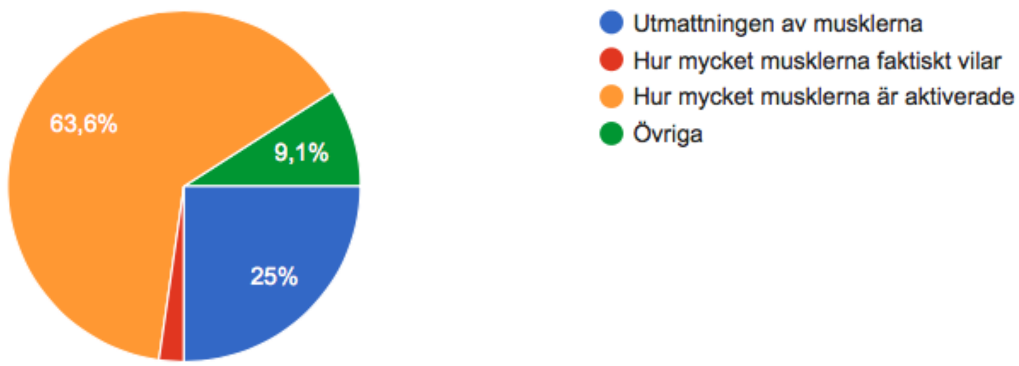
-Skulle du säga att ditt arbete är fysiskt krävande?



-Hur viktigt är det att produkten inte påverkar ditt arbete på en skala 1-10? (1 = inte alls, 10 = skulle påverka mig mycket)



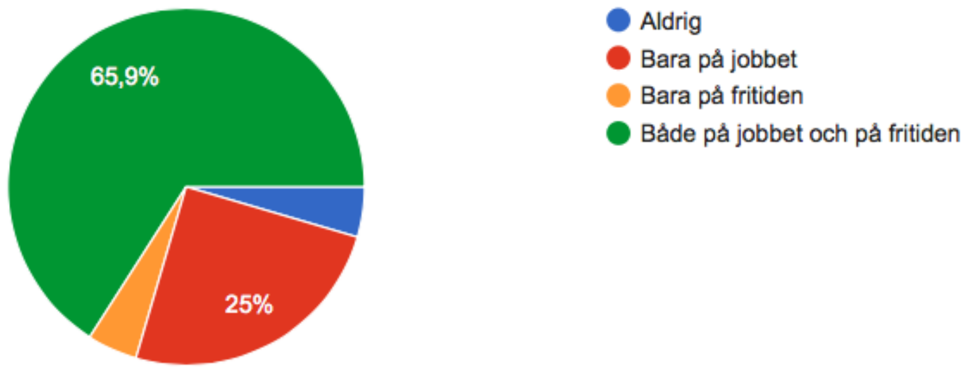
-Finns det någon speciell information du skulle vilja få ut om dina muskler?



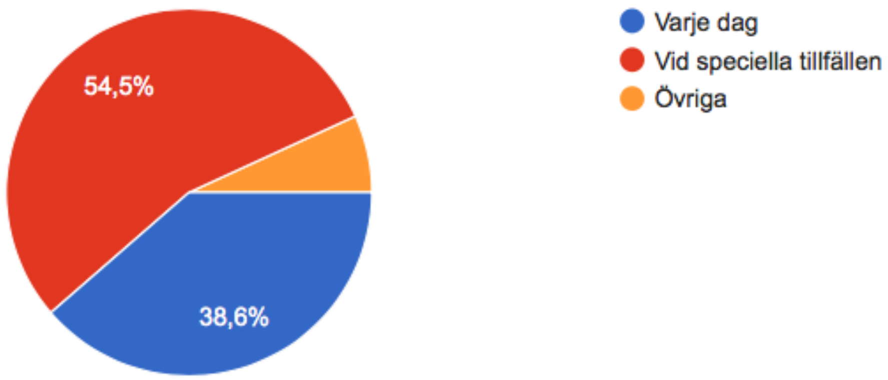
-Varför skulle du ha användning av en sådan produkt?

för att minska värk från arbetsrelaterade aktiviteter
Ergonomiskt korrekt arbete
För att upptäcka muskelskador
skulle vara intressant att veta vilka muskler aktiveras vid olika rörelse
Det hade kunnat förbättra min prestation, undvika skador och hjälpt till att träna rätt
För att få feedback om vad som är en bra arbetsställning då det är många tunga förflyttningar
För att behålla hälsan
Ur träning och kostperspektiv
För att öka sin kunskap kring hur ergonomisk man är i olika situationer.
För att veta om man överbelastar visa muskler
För att se hur pass mycket mina muskler är aktiva
För bättre koll av min hällsa
För att kunna utveckla dem andra muskler.
Förbättra mig själv
För att veta vilka positioner som är mer eller mindre gynnsamma
Intresse
För att kunna se vilka muskler som behöver prioriteras vid träning för att förebygga skador
För att motverka framtida skador
Jag vill minimera arbetets inverkan på mitt fysiologiska kapital.
När man har ont.
Skulle inte ha det
För att få kroppsbalans
Undvika förslitningsskador p.g.a monotona rörelser över en längre tid, vilket i sin tur kan leda till långtidssjukskrivning.
För att mår bättre
Se om ja t.ex. spänner nackmuskler i onödan på kontoret.
Se vilka muskler som aktiveras och därmed se vilka muskler jag behöver stärka upp för att kompensera

-När skulle du kunna tänka dig använda en sådan produkt?



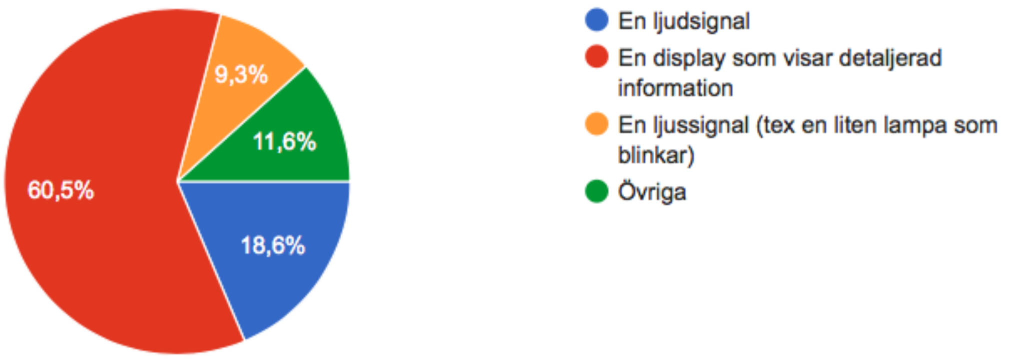
-Hur ofta skulle du kunna tänka dig använda en sådan produkt?



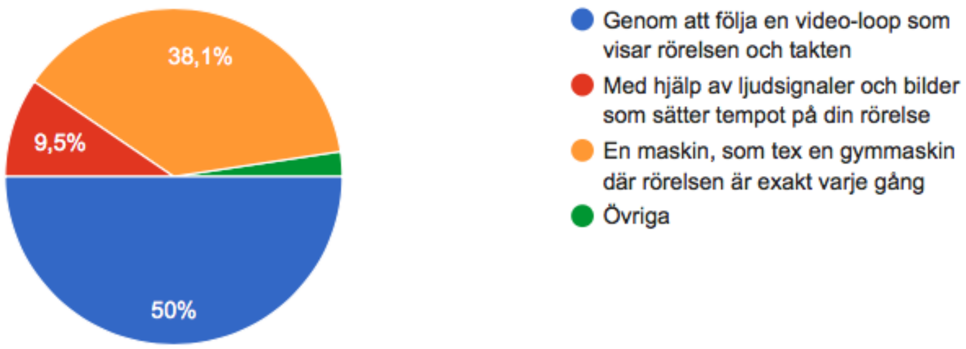
-Om du inte svarade ”varje dag” på förra frågan, vad skulle krävas för att du skulle använda produkten varje dag på jobbet eller fritiden eller både och?

Att den är användarvänlig, bekväm och att den inte begränsar mina dagliga aktiviteter.
Kort period
Vid sjukdom eller jobb skadan
Att jag hade långvariga besvär eller konstant smärta som jag måste jobba med
Att den inte är i vägen, att den är lätt och att designen är snygg.
Att den är enkel och smidig att använda
Att den är lätt att ta på/av, rengöra, ladda, kan föra över datan till ex mobilen.
Om den var så pass liten och smidig att den inte syns
Att jag såg en stark koppling till, och möjlighet att förbättra min prestationsförmåga. Samt att produkten inte störde mig på något sätt.
Att den ej påverkar vare sig fritid eller arbete, lättanvänd
Pengar

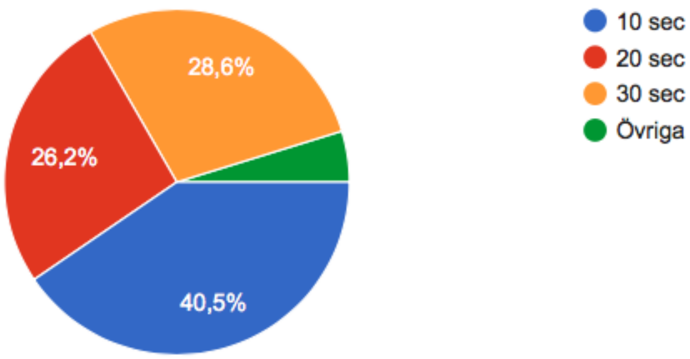
-Om produkten kunde förutspå potentiella problem musklerna, hur skulle du då vilja ta del av informationen?



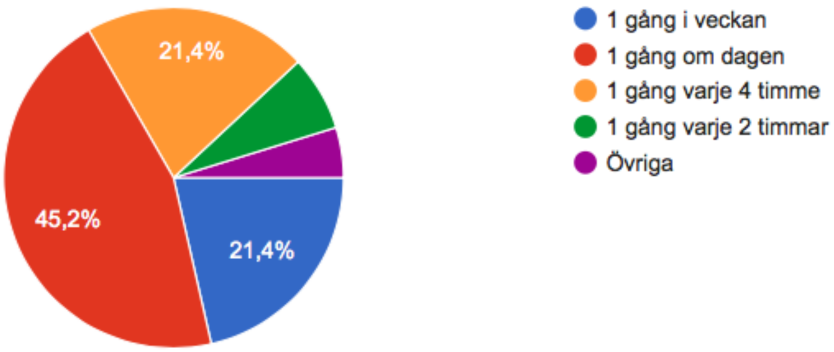
-För att kunna upptäcka potentiella muskelskador så kan det krävas att produkten mäter din kropps muskelaktivitet då en kontrollerad rörelse utförs med kroppen. Hur skulle du kunna tänka dig utföra den rörelsen?



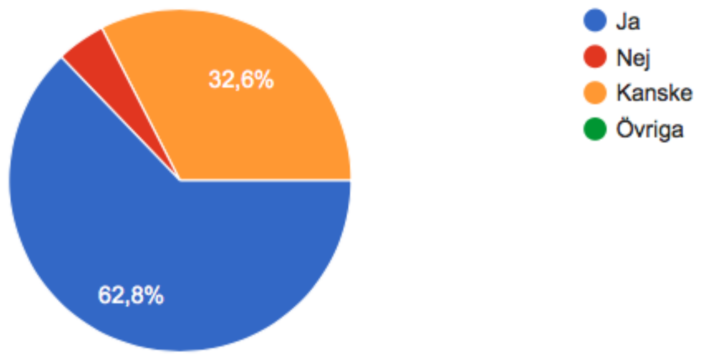
-Hur långt tid får denna rörelsen ta?



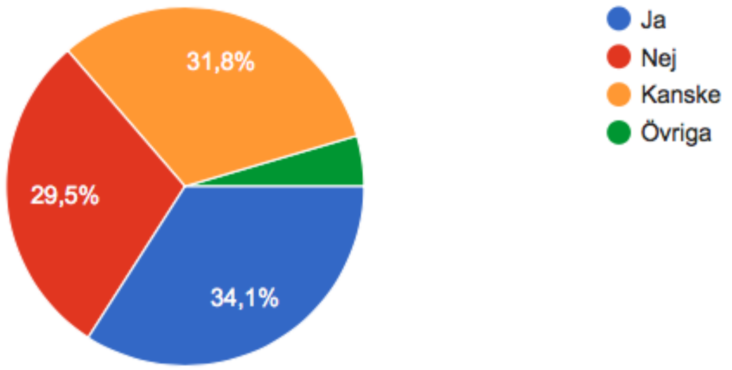
-Hur ofta skulle du kunna tänka dig utföra denna rörelsen? (Ju fler gånger desto bättre blir analysen av dina muskler)



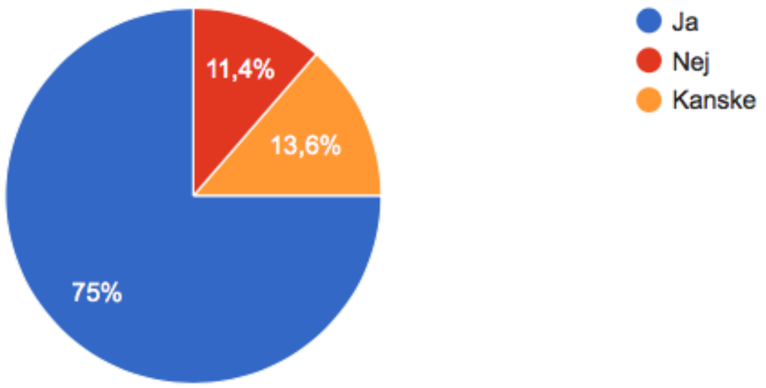
-Skulle det vara okej om arbetsgivaren tog del av datan som samlas in från musklerna för att tex. kunna förbättra arbetssituationen?



-Skulle du kunna tänka dig fylla i information om din hälsa (med avseende på musklerna) om det tog 5 min per dag?



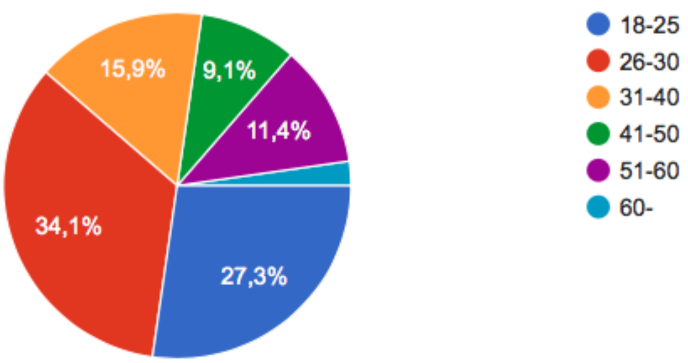
-Skulle du då kunna tänka dig att använda en applikation på en bärbar enhet?



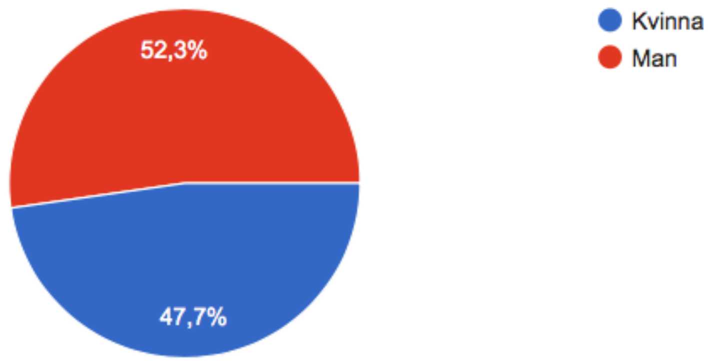
-Vad är viktigt att appen skulle innehålla? (tex. graf som visar aktivitetsnivån, daglig feedback på muskelhälsan osv.)

Inbyggd display
Inbyggd display
Det ska vara enkelt
Daglig feedback
Graf är bra via app och inte i skärm på produkten
Lätt avläsligt resultat med tidpunkt för klockslag när jag gjorde något fel och korrigerande feedback
Föredrar app i mobilen
Appen kanske kan ge tips på övningar som kan vara skadeförebyggande för de muskelgrupper som produkten upptäckt varit väldigt aktiva. Alltså att produkten är kopplad till appen.
Helst en inbyggd diplay
En graf
När mina muskler är aktiva/vila och vilka muskler. Vill ha det på en disaplay.
Små sensorer som mäter värmen utav musklerna.
Inbyggd display
Aktivitetsnivå främst. Hellre en app än en inbyggd display
Graf med information
Vill inte ha nån app
inbyggd display med kärninformationen synlig och mindre prioriterad information några klick borta. Graf idén ställer jag mig tveksam till.
Visuell daglig feedback. Grafer tabeller etc
Grafer, tabeller, /sånt som gör det lättförståeligt

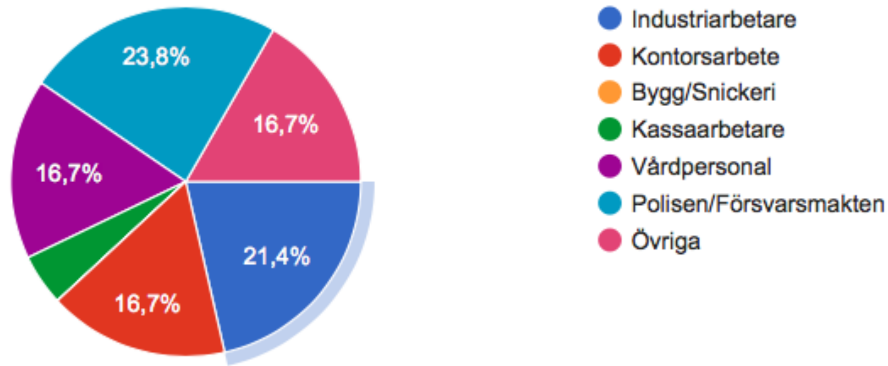
-Din ålder?



-Kön?



-Inom vilket område arbetar du?



B - INITIAL REQUIREMENTS SPECIFICATION

#	Demand/wish	Specifications: Muscle monitoring product	Requirement	Target	Unit	Verifying	Fulfilled?
1	Demand	Transmit result from sensors to monitor	Pass	Pass	Binary	Test	yes
2	Demand	Function with low amount of gel	Pass	no gel	Binary	Test	
3	Demand	Distance range of sender/reciever	x > 50	x > 100	m	Test	
4	Demand	Complies with IP67 class requirements	Pass	Pass	Binary	Test	
5	Demand	Meet Legal requirements and standards (Concept specific)***	Pass	Pass	Binary	Standard defined test	
6	Demand	Comfortable to use	Pass	Pass	Binary	Mock-up and testing with potential customers	yes
7	Demand	weight of product	500	300	gram	Test	yes
8	Demand	Materials are able to withstand outdoor environment	Pass	Pass	Binary	Test	
9	Demand	Reusable	Pass	Pass	Binary	Test	yes
10	Demand	Washable	Pass (handwash)	Pass (Machine wash)	Binary	Test	
11	Demand	Time to install	x ≤ 5	x ≤ 2	Min	Test	yes
12	Demand	Fastening removal time	x ≤ 1	x ≤ 0,5	min	Test	yes
13	Demand	Can be recycled	≤50%	≤100%	kg	Analyse	
14	Demand	Shock resistance	drop from 1,5 m*	drop from 2m*	m	Test	
15	Demand	Reference movement time	x ≤ 30	x ≤ 10	sec	Test	
16	Demand	Reference movement, amount of times per week**	once every 4th h	once every 168th h	times/h	Mock-up and testing with potential customers	
17	Demand	Design prevents user from harming themselves	Pass	Pass	Binary	Evaluation	yes
18	Wish	Provide hassle free link	"wireless" with wires on sensors	completely wireless	pcs.	Mock-up and testing with potential customers	yes
19	Demand	Ease of locating the correct position	within 1 cm from "best" spot	within 3 cm from "best" spot	cm	Mock-up and testing with potential customers	yes
20	Wish	Pre monitoring time (from pick-up to start monitoring)	x ≤ 5	x ≤ 2	min	Test	yes
21	Wish	Post monitoring time (from removal to storage)	x ≤ 5	x ≤ 2	min	Test	yes
22	Demand	Intuitive to use	Pass	Pass	Binary	Mock-up and testing with potential customers	
23	Wish	Visual feedback	Pass	Pass	Binary	Mock-up and testing with potential customers	yes
24	Demand	Product tickness	x ≤ 15	x ≤ 10	mm	Measurement	
25	Demand	Product depth	x ≤ 20	x ≤ 10	mm	Measurement	
26	Demand	Product length	x ≤ 20	x ≤ 10	mm	Measurement	
			*** on to concrete**				
			**** if used 24/7 so 168= 1 week**				
			***** final product wont be taken in to large consideration now**				

C - FINAL REQUIREMENTS SPECIFICATION

#	Demand/wish	Specifications: Muscle monitoring product	Component	Requirement	Target	Unit	Verifying	Fulfilled?
1	Demand	Transmit result from sensors to monitor	Puck	Pass	Pass	Binary	Test	yes
2	Demand	Function without gel	Electrode	Pass	Pass	Binary	Test	
3	Demand	Distance range of sender/reciever	Puck & Wristband	x > 50	x > 100	m	Test	
4	Demand	Complies with concept specific IP67 class requirements	Entire product	Pass	Pass	Binary	Test	
5	Demand	Meet Legal requirements and standards (Concept specific)***	Entire product	Pass	Pass	Binary	Standard defined test	
6	Demand	Comfortable to use	Entire product	Pass	Pass	Binary	Mock-up and testing with potential customers	yes
7	Demand	weight of product	Entire product	x ≤ 500	x ≤ 300	gram	Test	yes
8	Demand	Materials are able to withstand outdoor environment	Entire product	Pass	Pass	Binary	Test	
9	Demand	Reusable	Entire product	Pass	Pass	Binary	Test	yes
10	Demand	Washable in washing machine	Compression shirt & electrode	Pass (30 degree handwash setting)	Pass (40 degree regular setting)	Binary	Test	
11	Demand	Time to install	Entire product	x ≤ 5	x ≤ 2	Min	Test	yes
12	Demand	Time to answer questions on display about individuall health	Wristband (application	x ≤ 5	x ≤ 1	Min	Mock-up and testing with potential customers	yes
13	Demand	Fastening removal time	Entire product	x ≤ 1	x ≤ 0,5	min	Test	yes
14	Demand	Can be recycled	Entire product	x ≤ 50%	x ≤ 100%	kg	Analyse	
15	Demand	Shock resistance	Puck	drop from 1,5 m*	drop from 2m*	m	Test	
16	Demand	Reference movement time	Entire product	x ≤ 30	x ≤ 10	sec	Test	
17	Demand	Reference movement, amount of times per week**	Entire product	once every 4th h	once every 168th h	times/h	Mock-up and testing with potential customers	
18	Demand	Design prevents user from harming themselves	Entire product	Pass	Pass	Binary	Evaluation	yes
19	Wish	Provide hassle free link	Entire product	"wireless" with wires on sensors	completely wireless	pcs.	Mock-up and testing with potential customers	yes
20	Demand	Ease locating the correct position	Entire product	within 1 cm from "best" spot	within 3 cm from "best" spot	cm	Mock-up and testing with potential customers	yes
21	Wish	Pre monitoring time (from pick-up to start monitoring)	Entire product	x ≤ 5	x ≤ 2	min	Test	yes
22	Wish	Post monitoring time (from removal to storage)	Entire product	x ≤ 5	x ≤ 2	min	Test	yes
23	Demand	Intuitive to use	Entire product	Pass	Pass	Binary	Mock-up and testing with potential customers	
24	Demand	Impedance, skin-to-electrode	Electrode	x ≤ 10	x ≤ 5	kOhm	Test	
25	Wish	Visual feedback	Entire product	Pass	Pass	Binary	Mock-up and testing with potential customers	yes
26	Demand	Product thickness	Puck & attachment point	x ≤ 15	x ≤ 10	mm	Measurement	
27	Demand	Product depth	Puck & attachment point	x ≤ 20	x ≤ 10	mm	Measurement	
28	Demand	Product length	Puck & attachment point	x ≤ 20	x ≤ 10	mm	Measurement	
29	Demand	Battery life of the product	Puck	x > 10	x > 24	h	Test	
30	Demand	Battery life of the product	Wristband	x > 24	x > 48		test	
31	Demand	Sample rate	Puck	x = 1000	x > 1000	Hz	Test	
32	Demand	Noise	Electrode	x ≤ 5	x ≤ 1	uV (RMS, R.T.I.)	Test	
33	Demand	Resolution	Puck	16-bits A/D converter		bits	Test	
34	Demand	Bandwidth	Electrode	20-450	0-500	Hz	Test	
35	Demand	Temperature-range	Electrode	0-40	-15-50	C	Test	
36	Demand	PreAmplificationGain	Electrode	5±1%	10±1%	VN	Test	
37	Demand	Input impedance	Electrode	x = 10,000,000M	x > 10,000,000M	Ohm	Test	
38	Demand	Memory	Wristband	x□□ □≥ 2	x ≥ 4	GB	Test	
39	Demand	Prossecor	Wristband	Snapdragon 400 or similar (1,2 GHz)	x > 1,2 GHz	GHz	Test	
40	Demand	Breathable stretch fabric	Compression shirt	Pass	Pass	Binary	Analyse	
41	Demand	"Anti odour" Technology	Compression shirt	Pass	Pass	Binary	Analyse	
42	Demand	Long and short sleeve	Compression shirt	Pass	Pass	Binary	/	Yes
				*** on to concrete**				
				**** if used 24/7 so 168= 1 week**				
				***** final product wont be taken in to large consideration now**				

D - ELIMINATION MATRIX

Elimination matrix for: Muscle Monitoring								Criteria fulfilment: (+) Yes (-) No (?) More info needed	
Concept name	Concept number	Solves main problem	Fulfills all demands	Feasable	Reasonable cost	Safe	Enough information	Comments	Decision
Butterfly patch (daniel 1)	1	+	+	+	+	+	+		further develop
Compression shirt (daniel 2)	2	+	+	+	?	+	-		further develop
Back plate (daniel 3)	3	+	+	+	+	+	-		further develop
Smart textile shirt (daniel 4)	4	+	+	-	-	+	-	Smart textiles are not developed to that level yet	Kill
Butterfly patch with smartwatch (daniel 5)	5	+	+	+	+	+	+		further develop
Puck attack (christofer 1)	6	+	+	+	-	+	+	User, expansive if many sensors needed	further develop
Protection gear (christofer 2)	7	+	-	+	-	+	+	User, expansive if many sensors needed	Kill
Net shirt (christofer 3)	8	+	?	?	-	+	-	Unknown and complicated technology	Kill
The sensor puck (christofer 4)	9	+	+	+	+	+	+	Simple product	further develop
The back sheild (christofer 5)	10	+	-	+	-	+	+	not comfortable	Kill
Puck attack single (christofer 6)	11	+	+	+	+	+	+		further develop
The sensor puck tape (christofer 7)	12	+	+	+	+	+	+	simple product	further develop

patch 4,5,4c,7c
compression 2,2c,1c,6c
plates 3,5c
others 4, 3c

E - PUGH MATRIX

FIRST ITERATION

Criterion	Concept								NOTES
	Butterfly Patch	Compression shirt	Back Plate	Butterfly patch with smartwatch	Puck attack	The sensor puck	Puck attack single	The sensor puck tape	
Transmit result from sensors to monitor	0	0	0	0	REFERENCE	0	0	0	
Function with low amount of gel	−1	0	0	−1		−1	0	−1	
Complies with concept specific IPXX class requirements	−1	0	0	−1		−1	0	−1	
Comfortable to use	−1	1	1	−1		−1	1	−1	
Time to install	−1	1	1	−1		−1	1	−1	
Fastening removal time	−1	1	1	−1		−1	1	−1	
Shock resistance	0	0	0	0		0	0	0	
Design prevents user from harming themselves (wristbands are harmful)	0	−1	0	−1		−1	0	−1	
Ease locating the correct position	−1	0	0	−1		−1	0	−1	
Intuitive to use	0	0	0	0		−1	0	−1	
Reusable	0	0	0	0		0	0	0	
Washable/cleanable	0	0	0	0		0	0	0	
Replacable parts to enable furhter income during product lifecycle	1	0	0	1		1	0	1	
Provide hassle free link	0	0	0	0		0	0	0	
Visual feedback	0	1	0	1		1	0	1	
Modularity	−1	0	−1	−1		0	0	0	
Sum +	1	4	3	2		2	3	2	
Sum 0	8	11	12	6		6	13	6	
Sum -	7	1	1	8		8	0	8	
Net value	−6	3	2	−6		−6	3	−6	
Ranking	4	1	3	4		4	1	4	
Further development?	kill	further dev.	further dev.	kill	further dev.	kill	further dev.	kill	

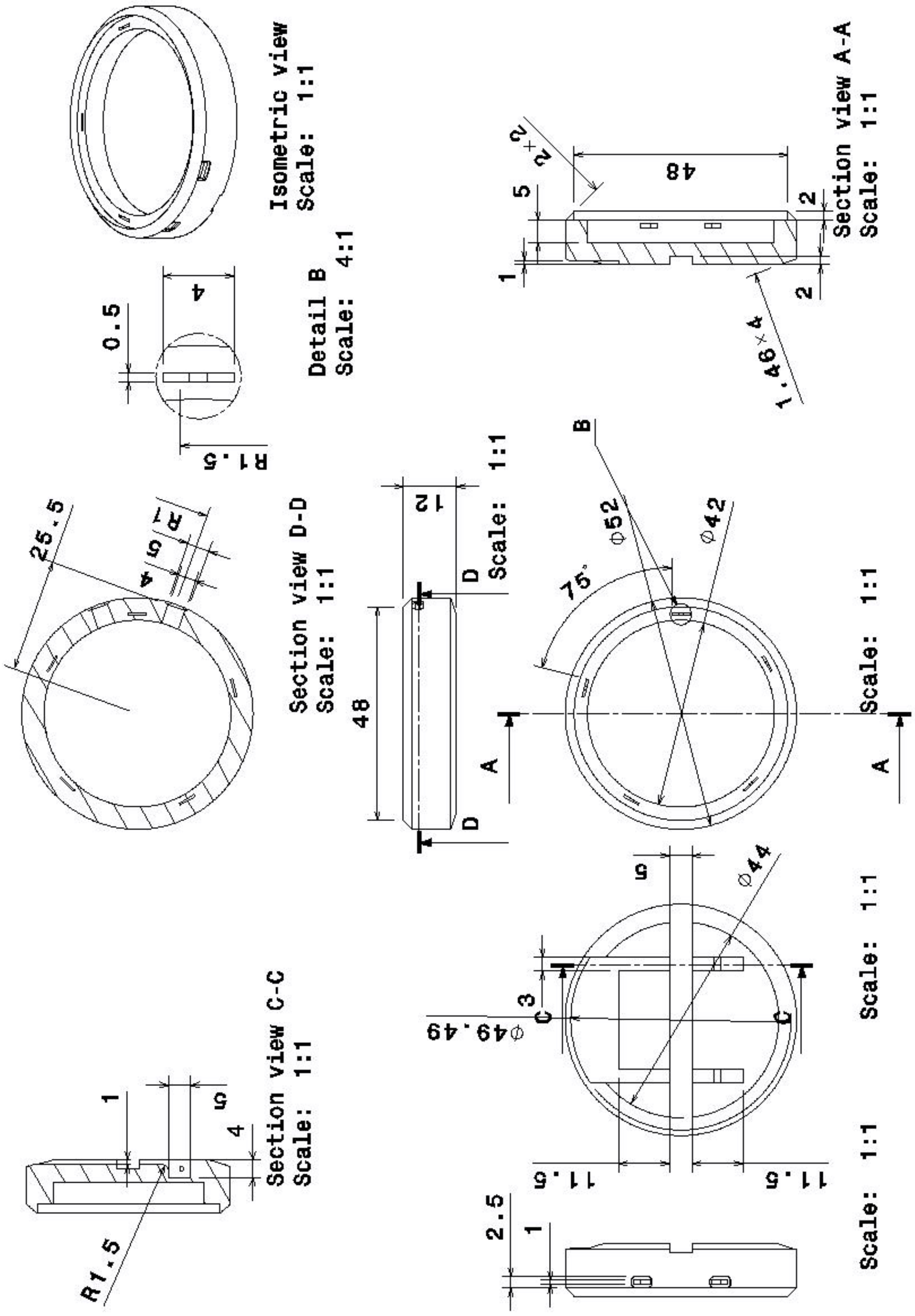
SECOND ITERATION

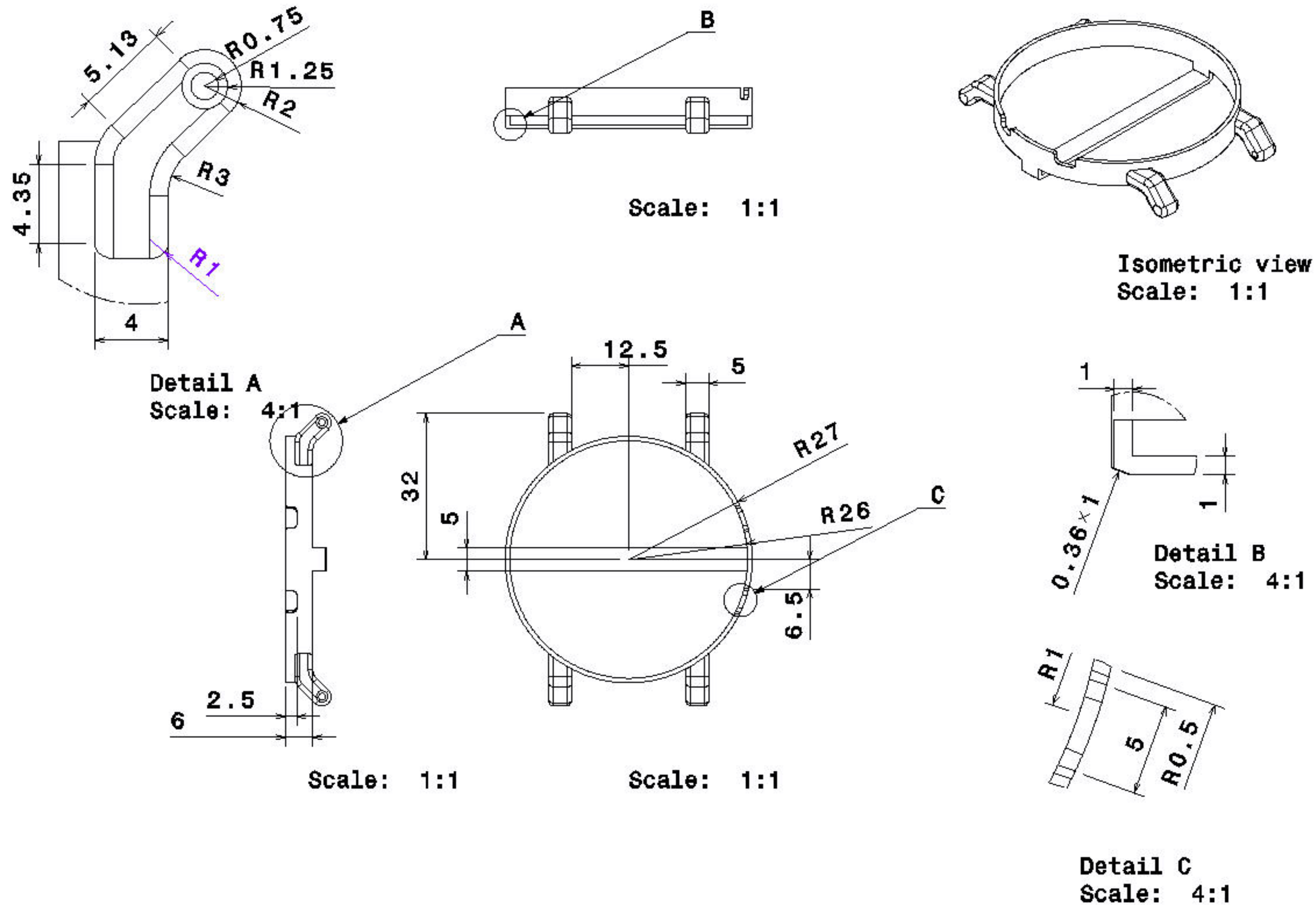
Criterion	Concept								NOTES
	Butterfly Patch	Compression shirt	Back Plate	Butterfly patch with smartwatch	Puck attack	The sensor puck	Puck attack single	The sensor puck tape	
Transmit result from sensors to monitor	0	REFERENCE	0	0	0	0	0	0	
Function with low amount of gel	−1		0	−1	0	−1	0	−1	
Complies with concept specific IPXX class requirements	−1		0	−1	0	−1	0	−1	
Comfortable to use	−1		−1	−1	−1	−1	0	−1	
Time to install	−1		0	−1	−1	−1	0	−1	
Fastening removal time	−1		0	−1	−1	−1	0	−1	
Shock resistance	0		0	0	0	0	0	0	
Design prevents user from harming themselves (wristbands are harmful)	1		1	0	1	0	1	0	
Ease locating the correct position	−1		0	−1	0	−1	0	−1	
Intuitive to use	0		0	0	0	−1	0	−1	
Reusable	0		0	0	0	0	0	0	
Washable/cleanable	0		0	0	0	0	0	0	
Replacable parts to enable furhter income during product lifecycle	1		0	1	0	1	0	1	
Provide hassle free link	0		0	0	0	0	0	0	
Visual feedback	−1		−1	0	−1	0	−1	0	
Modularity	−1		−1	−1	0	0	0	0	
Sum +	2		1	1	1	1	1	1	
Sum 0	6		12	7	11	8	14	8	
Sum -	8		3	7	4	7	−1	7	
Net value	−6		−2	−6	−3	−6	0	−6	
Ranking	4		2	4	3	4	1	4	
Further development?	kill	further dev.	further dev.	kill	further dev.	kill	further dev.	kill	

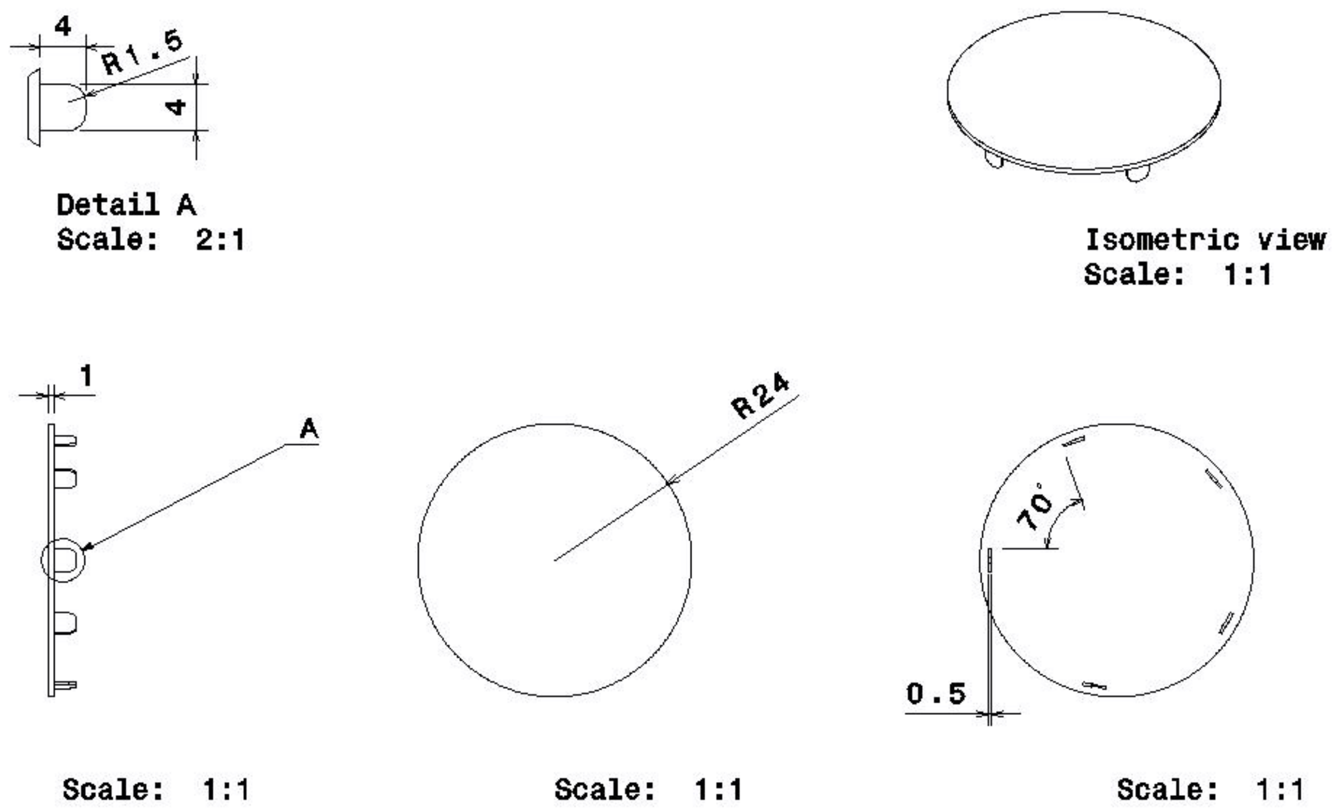
F - KESSELRING MATRIX

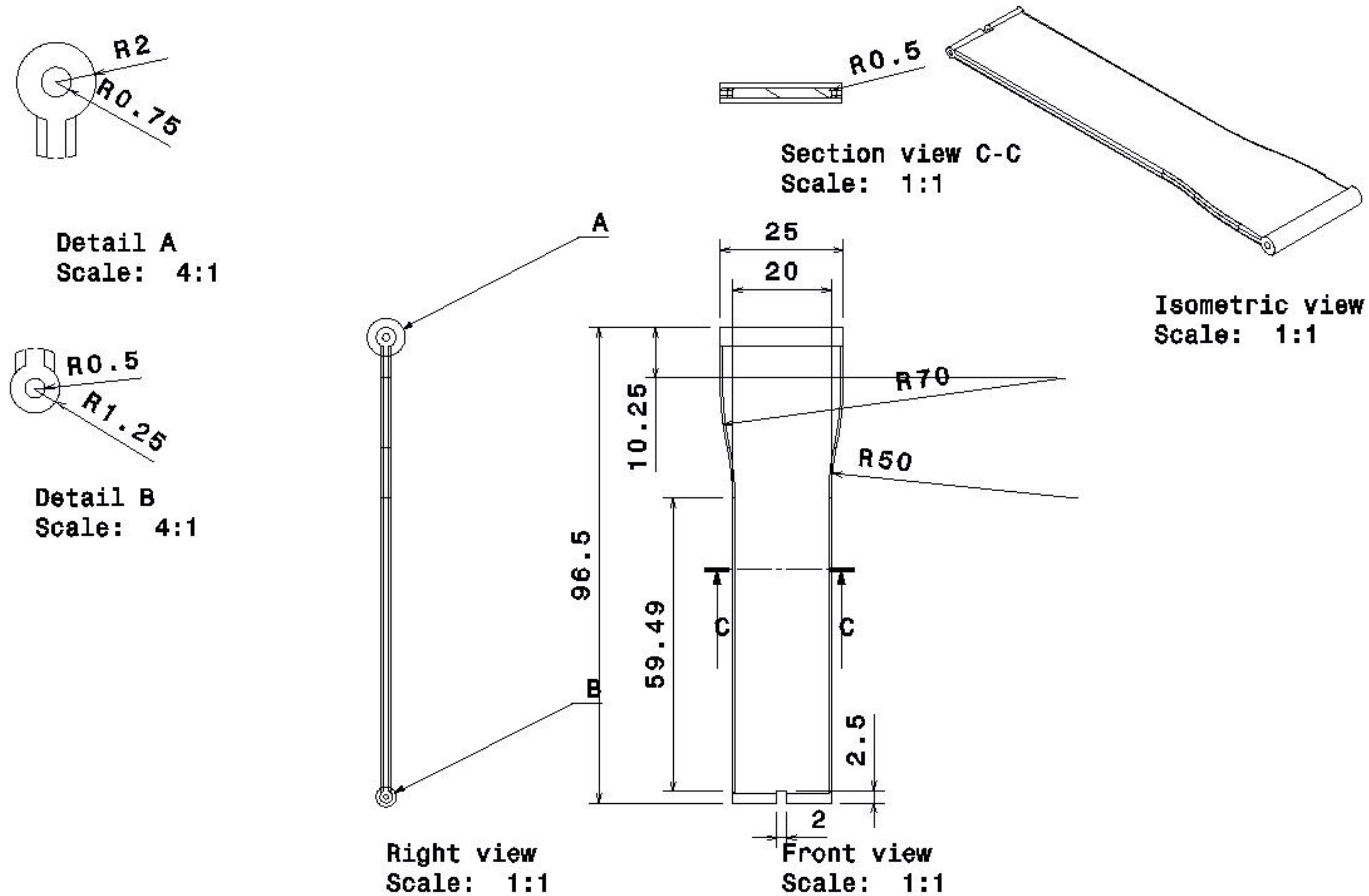
Chalmers		Kesselring Matrix: Muscle Monitoring									
Issuer: Muscle Monitoring group				Created 2016-12-14				Modified x			
Criteria		Concepts									
		Ideal		Compression shirt		Back plate		Puck attack		Puck attack single	
Type	w	v	t	v	t	v	t	v	t	v	t
Transmit result from sensors to monitor	3	5	15	5	15	5	15	5	15	5	15
Function with low amount of gel	3	5	15	5	15	5	15	5	15	5	15
Complies with concept specific IPXX class requirements	4	5	20	5	20	5	20	5	20	5	20
Comfortable to use	5	5	25	5	25	3	15	3	15	5	25
Time to install	5	5	25	5	25	3	15	4	20	5	25
Fastening removal time	4	5	20	5	20	3	12	4	16	5	20
Shock resistance	4	5	20	4	16	4	16	4	16	4	16
Design prevents user from harming themselves (wristbands are harmful)	3	5	15	3	9	5	15	5	15	5	15
Ease locating the correct position	4	5	20	4	16	3	12	4	16	4	16
Intuitive to use	5	5	25	5	25	4	20	4	20	5	25
Reusable	3	5	15	5	15	5	15	5	15	5	15
Washable/cleanable	3	5	15	5	15	5	15	5	15	5	15
Replacable parts to enable furhter income during product lifecycle	2	5	10	1	2	1	2	1	2	1	2
Provide hassle free link	4	5	20	5	20	5	20	5	20	5	20
Visual feedback	5	5	25	5	25	3	15	3	15	3	15
Modularity	2	5	10	5	10	1	2	5	10	5	10
Total		80	**295**	72	**273**	60	**224**	67	**245**	72	**269**
Ranking			**1**		**2**		**5**		**4**		**3**

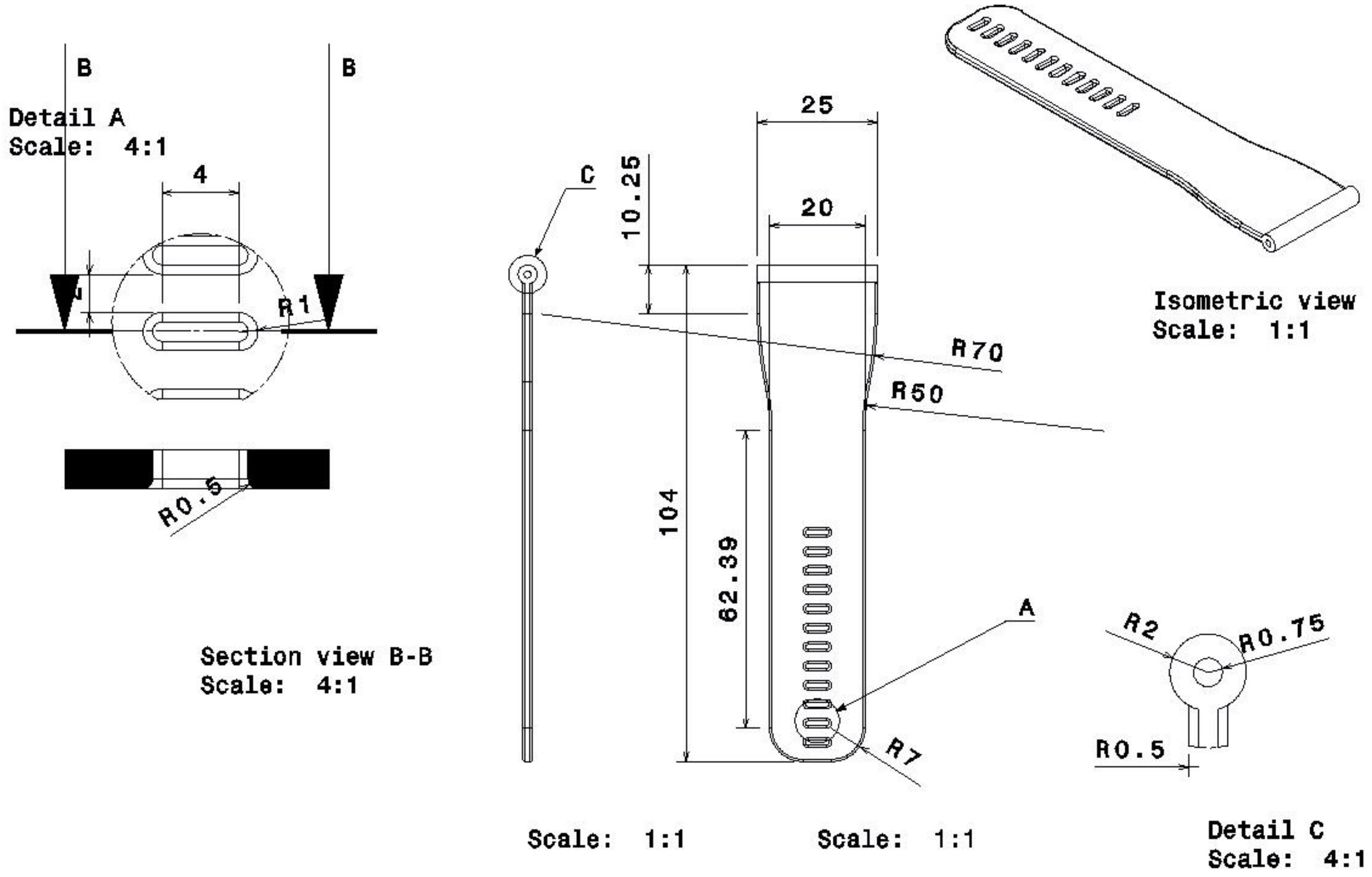
G - DRAWINGS

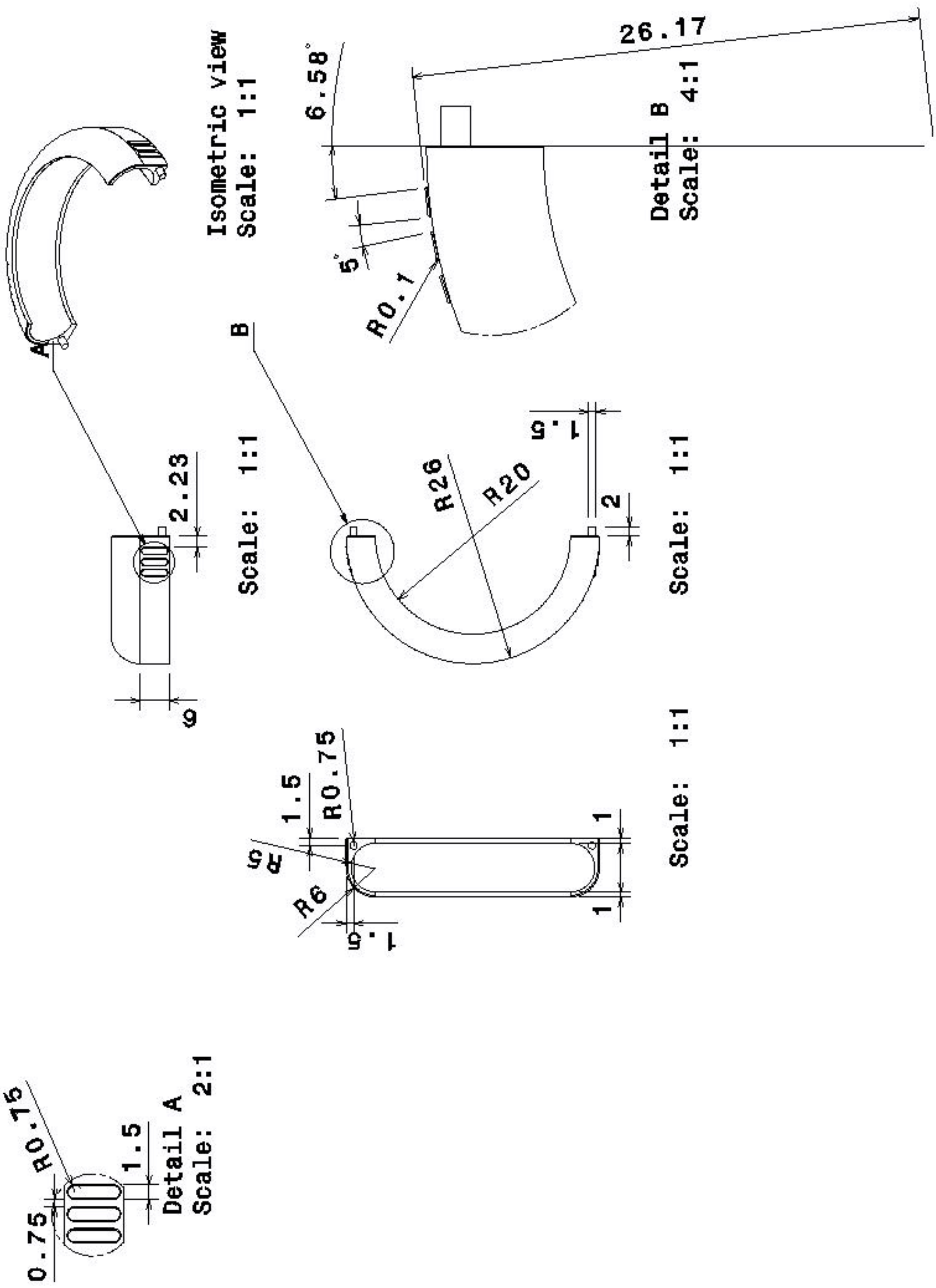

Isometric view
Scale: 1:1
Detail B
Scale: 4:1
0.5
4
R1.5
Section view A-A
Scale: 1:1
48
5
2×2
1
2
2
1.46×4
Section view D-D
Scale: 1:1
25.5
R1
5
4
Section view
Scale: 1:1
48
12
Scale: 1:1
D
D
B
ϕ52
ϕ42
75°
A
A
Scale: 1:1
Section view C-C
Scale: 1:1
1
5
4
R1.5
ϕ49.49
3
C
C
5
ϕ44
11.5
11.5
Scale: 1:1
2.5
1
Scale: 1:1

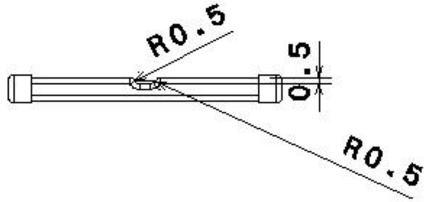

5.13
R0.75
R1.25
R2
R3
4.35
R1
4
Detail A
Scale: 4:1
B
Scale: 1:1
Isometric view
Scale: 1:1
A
12.5
5
32
5
R27
R26
C
6.5
2.5
6
Scale: 1:1
Scale: 1:1
1
1
0.36×1
Detail B
Scale: 4:1
R1
5
R0.5
Detail C
Scale: 4:1


4
R1.5
4
Detail A
Scale: 2:1
Isometric view
Scale: 1:1
1
A
R24
70°
0.5
Scale: 1:1
Scale: 1:1
Scale: 1:1

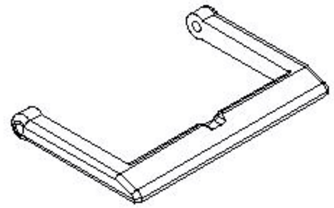

R2
R0.75
Detail A
Scale: 4:1
R0.5
R1.25
Detail B
Scale: 4:1
A
B
Right view
Scale: 1:1
R0.5
Section view C-C
Scale: 1:1
25
20
10.25
96.5
59.49
R70
R50
C
C
2.5
2
Front view
Scale: 1:1
Isometric view
Scale: 1:1


B
B
Detail A
Scale: 4:1
4
R1
R0.5
Section view B-B
Scale: 4:1
C
10.25
25
20
R70
R50
104
62.39
A
R7
Scale: 1:1
Scale: 1:1
Isometric view
Scale: 1:1
R2
R0.75
R0.5
Detail C
Scale: 4:1

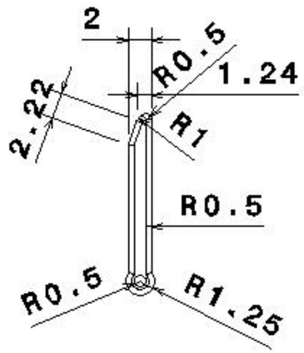

Isometric view
Scale: 1:1
Detail B
Scale: 4:1
26.17
6.58°
5°
R0.1
B
A
2.23
Scale: 1:1
6
R26
R20
1.5
2
Scale: 1:1
1.5
R0.75
R5
R6
1.5
1
1
Scale: 1:1
R0.75
1.5
0.75
Detail A
Scale: 2:1



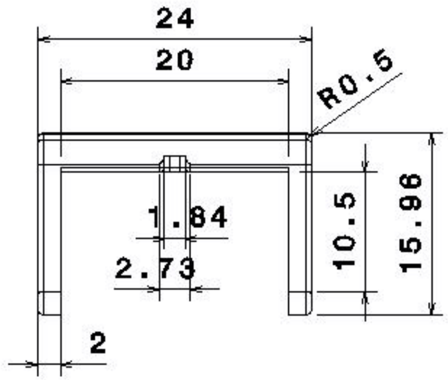
Scale: 2:1



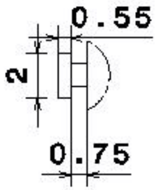
Isometric view
Scale: 2:1



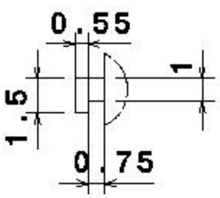
Scale: 2:1



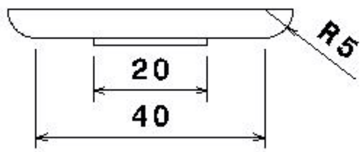
Scale: 2:1



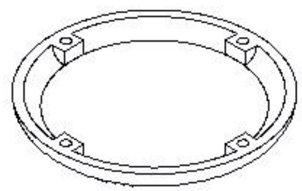
Detail A
Scale: 4:1



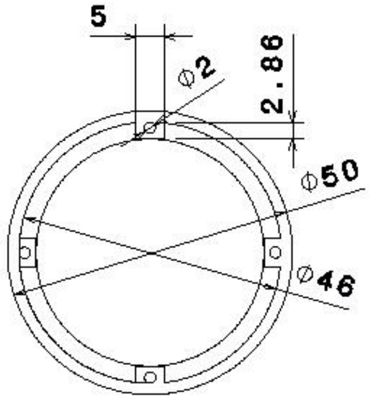
Detail B
Scale: 4:1



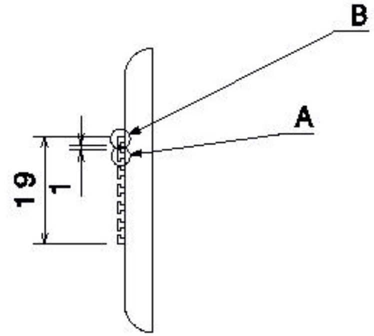
Scale: 1:1



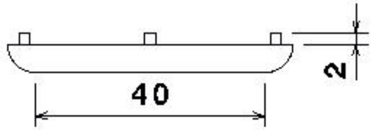
Isometric view
Scale: 1:1



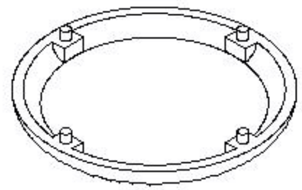
Scale: 1:1



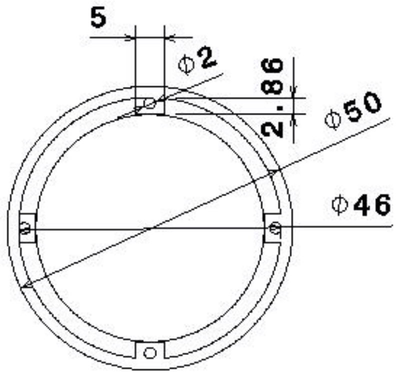
Scale: 1:1



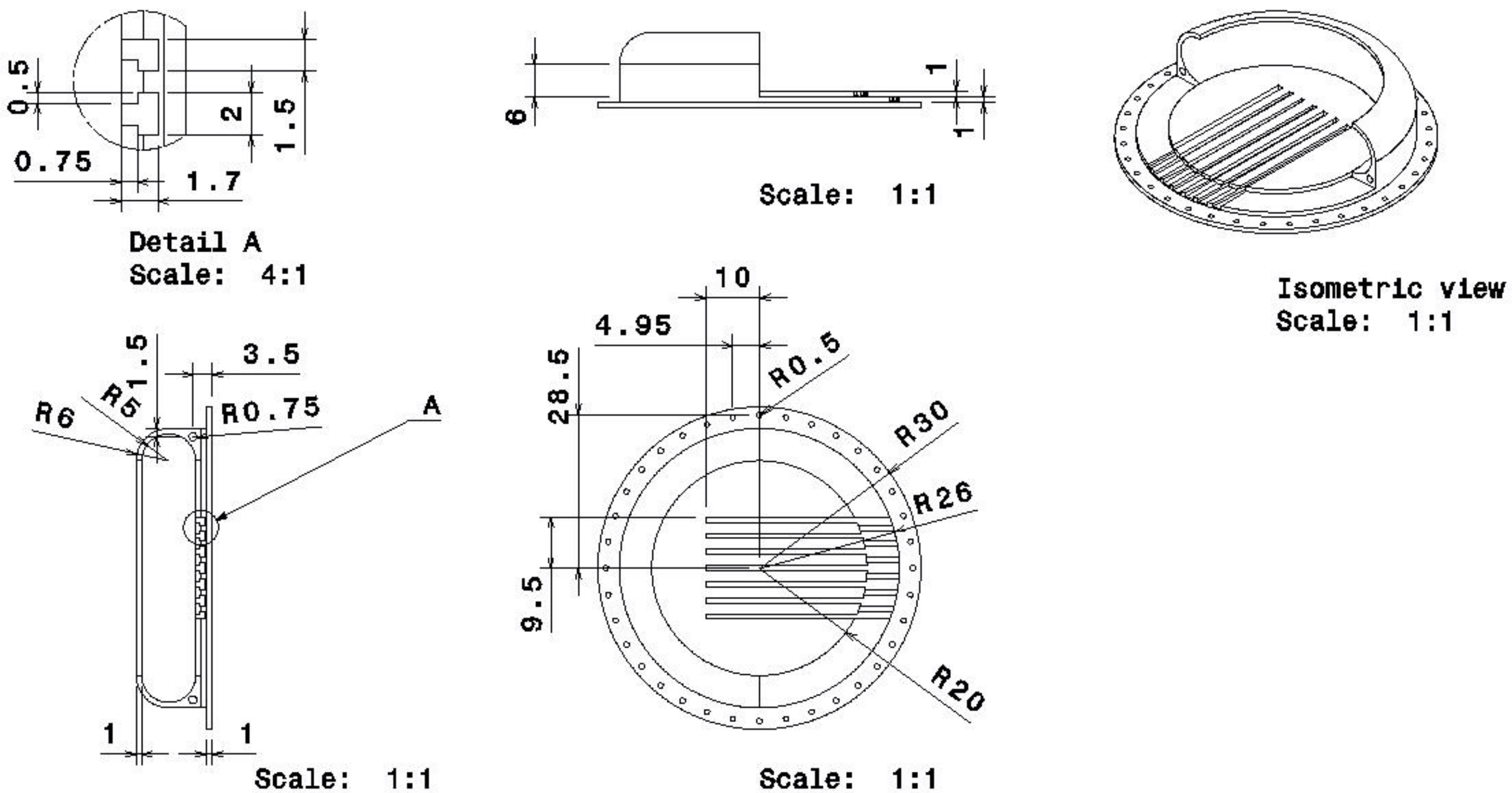
Scale: 1:1



Isometric view
Scale: 1:1



Scale: 1:1


0.5
2
1.5
0.75
1.7
Detail A
Scale: 4:1
6
1
1
Scale: 1:1
Isometric view
Scale: 1:1
R6
R5
1.5
3.5
R0.75
A
1
1
Scale: 1:1
10
4.95
R0.5
28.5
R30
R26
9.5
R20
Scale: 1:1

H - TEST PROTOCOL

Experiment test protocol for EMG monitoring of muscle fatigue during dynamic movements.

Purpose:
Muscle fatigue is related to work related musculoskeletal disorders. Therefore the purpose of this experiment is to investigate the possibility of the ability to see the muscle fatigue of the trapezius muscle when carrying out a work task when monitoring the muscle with sEMG. The following ***hypothesis*** is stated: through monitoring the EMG signal from a subject, throughout a working day, signs of muscle fatigue can be seen.

Materials:
In order to be able to carry out the experiment the following items are needed:

- *One subject per session*
- *EMG equipment*
- *3 electrodes per session*
- *Computer with EMG recording software*
- *Video recorder*
- *Items to create a mockup of the working environment (e.g. table and chairs)*
- *2 Dumbbells with ability to change weights*
- *Elastic band for training*

Methods:
Conduct the the experiment with at least 4 different Subjects.
Duration of time: 10 repetitions and 5 sets.
Record following features: Frequency (Median Frequency, MDF), Amplitude, Electrical Activity, MVE, MVC.

The definition of MDF is given by:

$$\sum_{j=1}^{\mathrm{MDF}} P_j = \sum_{j=\mathrm{MDF}}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j \qquad (1),(2)$$

where P_j is the EMG power spectrum at the frequency bin j, and M is the length of frequency bin. (*Definition: Frequency at which 50% of the total power within the epoch is reached (3).)*

1. First of all prepare and **setup a mock-up environment** for given task working task if needed.

a. *Assembly of car door:* create a working space that symbolises the door opening in a car.
b. *Assembly of interior roof of car:* place a chair that the subject can sit in.
c. *Sawing:* Use a table as a working bench and fasten the elastic band.

Setup the EMG equipment. Connect all the cables to the EMG equipment and the computer. Connect all electrodes to the cables. Setup the video recording.

Subject answers a short survey with information about their activity levels. This is conducted in order to be able to see and understand the impact of this on the monitoring, such as the reference recording.

- Sex: Male Female Other
- Length: ....cm
- Weight: ....kg
- Do you usually work out?
- If yes how many times a week: …...times
- Do you feel well rested today? Yes No
- Have you done something physical demanding the last 24h? Yes No
- Do you have any problems with your arms, neck or back today? Yes No
- If yes, what kind of problem: ……………………………………………….

4. **Inform the subject** about the working task and the movements that should be fulfilled.

a. Assembly of car door:

- Place a dumbbell in each hand
- Lean forward
- Squeeze your body, as if you are working in a narrow space.
- Lift and push the dumbbells (hold them close to each other) straight forward.
- Wiggle your hands as if fastening the door.
- Put down the dumbbells.

b. Assembly of interior roof of car:

- Place a dumbbell in each hand
- Lift the dumbbells straight over your head, keep the elbow joint a bit bent.
- Perform a small movement back/forward as if you were positioning the roof.

Push your arms up as if you clicking the roof to its place.

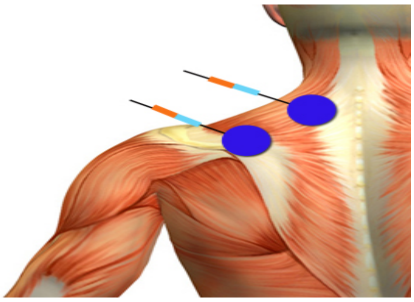
- Wiggle your hands as if fastening the roof.
- Put down the dumbbells.

c. Sawing:

- Grab the elastic band that symbolises the saw and move it towards you so it is extracted.
- Place the hand that is not holding the elastic band on the table as support.
- Lean forward with your upper body.
- Drag the arm with the elastic band back and forward for x minutes.

5. Place electrodes to the subject.

a. Trapezius:



6. Start recording video for observation.

7. **Record reference** with the EMG equipment. This should be conducted before the subject have lifted any dumbbells or used elastic band and is resting.

8. Start recording the EMG signal.

9. Let subject carry out the working task 10 times.

10. **Record the EMG signal while the subject resting** and have put down the dumbbells or the elastic band.

11. Redo steps 9 and 10, 4 times.

12. **Analyse results**, can muscle fatigue be distinguished in the signal?

Control treatment:
In order to be able to see increasing muscle fatigue a reference value from when subject is resting has to be recorded before the working task is performed.

Data interpretation:
Analyse the recordings from when the subject was resting in between the sets, is it possible to distinguished muscle fatigue? The recordings are plotted in a graph in order to see if fatigue in the muscle can be seen within the signal. If the muscle fatigue increases from before the working task is performed until the final recording, it can be concluded that this monitoring method can be used in a product.

References
1,http://www.intechopen.com/books/computational-intelligence-in-electromyography-analysis-a-perspective-on-current-applications-and-future-challenges/the-usefulness-of-mean-and-median-frequencies-in-electromyography-analysis
2, http://www.socsc.ktu.lt/index.php/elt/article/viewFile/3697/2348
3, https://www.biopac.com/wp-content/uploads/app118.pdf

I - MATLAB CODE

```
load('data')
data=data(4000:200000)
data=abs(data);
fs = 1000;
epochSize = 2000;
freqStep = 50; %Width of frequency bands
freqStart = 30; %Frequency to start with
pts = 1000; %Points over entire freq. range

%Calculate spectrogram over frequency bands
w = hamming(epochSize);
freq=freqStart:freqStep:fs/2;
freqRange=linspace(freq(1),freq(end),pts); %Compute frequency vector
bandInc=floor(length(freqRange)/(length(freq)-1)); %How many frequency points in each
band

%STFT of each sensor axis, will slide the window 50 samples at a time,
%producing one value for each second

S = spectrogram(data,w,epochSize-fs,freqRange,fs);
[p l] = size(S);
for j = 1:l
   for k = 1:bandInc:length(freqRange)-bandInc
      energy(k,j) = sum(abs(S(k:k+bandInc-1,j).^2)); %Sum STFT abs-squared to get energy
   end
end
energy( ~any(energy,2), : ) = [];
energy( :, ~any(energy,1) ) = [];
surf(energy)
c = colorbar;
xlabel('Time [s]')
ylabel('Frequency bands')
title(c,'Energy [J]');
```