Musculoskeletal disorders in the office environment: measuring the risk factors

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Bachelor thesis

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Musculoskeletal disorder (MSD) is an injury which causes a lot of problems among office workers. The risk factors of MSDs can be physical, psychosocial or individually medical. Very common risk factors include, poor ergonomics and long sedentary periods, leading to awkward postures and high burden for the musculoskeletal system. Besides that, repetitive movements of the arm caused by using the keyboard and mouse, can cause arm-wrist-hand and neck-shoulder issues. The highly stressful environment at the office could lead to psychosocial strain and is therefore also seen as a major risk factor. The challenge of using sensors to measure these risk factors, lies in the fact that the sensors need to be minimally invasive while still being able to detect clinical relevant changes. Nowadays, computer software and a force sensing mouse are used to measure the keyboard and mouse use, while electromyography (EMG) can indicate muscle fatigue and strain. At the same time, force sensing resistors can analyze sedentary periods and awkward postures. To detect stress, Polyvinylidene fluoride (PVDF) film sensors and electrocardiograms (ECG) are used, as they can give insight on heart rate variability (HRV). The goal of the product that is going to be developed, is that it can measure the different risk factors of musculoskeletal disorders. This way it can hopefully help to prevent the development of MSDs among office workers. As the project only lasts 10 weeks, there are multiple limitations to the project. The sensors will only be tested one at a time for their abilities, but not simultaneously. On top of that the data processing and energy sources will not be investigated. Lastly, it will not be able to link the risk factors to MSD development.

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1 Introduction

Musculoskeletal disorder (MSD) is an injury which is a very common problem among office workers.[i] In the United States alone, there are annually 70 million doctors' visits due to musculoskeletal disorders. Risk factors of MSDs can be both professional and non-professional and can also be referred to as work-related or non-work-related. [ii] Non-professional risk factors are for example the age of an employee. Logically, the muscles and joints have experienced high workload for a longer amount of time with increased age. Therefore, the risk of occurrence of MSD is higher. Amongst other things sex and overweight can play a role in the development of MSD. [iii] However, in most cases, MSDs are a result of multiple factors combined. Research has shown that risks can be physical, psychosocial and individually medical and often a mix of them.[iv] To try to link poor work place environments to MSD development, different methods can be used. These range from reports written by workers themselves, observation and recording of workspace hazards via for example video analysis and direct measurements by means of monitoring sensors.[iv] If you want to draw the right conclusions, these methods are ideally used simultaneously.[v]

One of the professional risk factors in the workplace, is poor ergonomics.[iii] Research based on self-recorded reports has shown that the ergonomic risk of MSDs rises when computers are used for more than four hours during the day.[i] When the body is held in a static, awkward position for multiple hours, the burden on the locomotor (musculoskeletal) system may become too high and MSDs as neck, shoulder and lower back problems may arise.[i,iii] On top of that, repetitive movements from using the keyboard can induce shoulder problems.[i] Self-reports however, can be biased because sometimes employees, accidentally, augment the time spend behind a computer per day. Further research did not show a significant relation between computer use and prolonged symptoms of MSDs when based on the computer software. At the same time, like many previous researches, it did show significance when based on self-reports.[vi] Therefore, for now computer usage for more than 4 hours is seen as a risk factor for MSD. Computer goes hand in hand with extensive mouse usage. When a mouse is used for more than 4 hours per work day, it could become a hazard for both arm-wrist-hand and neck-shoulder issues.[vii]

The last physical risk which is going to be investigated in this research, is being seated for a long time. This risk is united with working behind a computer for more than four hours, since that means that office workers are seated for the majority of the day. So far, most studies contradict each other on the association of low back pain (LBP) and the long, sedentary periods of office workers. This is mainly due to the fact that risks of MSDs are always based on multiple factors.[viii] Research based on questionnaires and a pressure mat fixed to chairs, have indicated an association, though minor ($p = 0.011$) between chronic LBP and static sitting behavior. The percentage of transient (non-sedentary) periods of partakers of the research who indicated chronic LBP was lower ($25.69 \pm 11.69\%$) than that of the partakers who did not suffer back pains ($35.23 \pm 14.55\%$). This is in agreement with earlier studies, which recommend frequent change of posture to reduce muscle fatigue and strain of the intervertebral discs caused by sitting statically.[viii] Prolonged sitting can induce too much spinal loading and thus decreased disc nutrition which could lead to higher vulnerability for back problems and therefore needs to be prevented.[ix,x] Changing posture regularly can release some of the load on the spine to prevent injury.[x] It can also help to reduce the excessive activity of major muscles as the trapezius, necessary to keep balance during static periods.

The strain on the muscles can lead to fatigue of the muscles and ultimately to injuries. As the posture, held when sitting behind a computer, often becomes a habit, these short breaks can also in times not be sufficient to reduce the risks of MSDs.[xi]

Aside from the physical impact caused by working at the office, there is also a psychological impact on the health of employees. Psychological strain, like stress, can affect the muscles and ultimately lead to MSDs. In office environments where computer work is very important, the demand is often high. On top of that, the lack of autonomy there often causes increased strain.[xii] These stress conditions could lie on the basis of MSD development, and should therefore be taken very seriously.

Current measurement techniques

When aiming for less musculoskeletal disorders among office workers, one should monitor the risks constantly. Measurement techniques are continuously evolving. For example, accelerometers attached to office workers can indicate their movements during the day and consequently indicate the time office workers spend being seated at their desk.[xiii] It is important that this device does not negatively affect the work performance of the employees. This means that it should not interfere with their range of motion or distract them from their tasks. Hence, we need to find a way to make it minimally invasive. Another way to investigate static and dynamic sitting behavior is by applying a pressure mat to the office chair, which can provide us with data on pressure points. Next to showing non-sedentary periods, it can also reveal whether the participants were sitting upright or tilted to one side more than the other.[xiv] These measurement techniques are combined with questionnaires on pain to be able to connect a certain sitting behavior to development of MSDs.[viii] They could also be combined with observational techniques as video analysis, which can give us information about both the angle and the velocities of the office workers' body movements.[iv]

The time office workers spend behind their computers is often overestimated when self-reports are used. Therefore, software recordings are preferred to provide data on keyboard and mouse use. By looking at the pauses (for example longer than 30 seconds) between either clicking or moving the mouse or using the keyboard, information is gathered on the total computer use per day. In combination with for example a Nordic questionnaire on possible symptoms, the effect of computer use on musculoskeletal disorders can be investigated.[vi] During the COVID-19 pandemic, the risks on development of MSDs possibly have gotten bigger, since many office workers are now working from home. Research suggests that due to the increased use of laptops instead of monitors, and simultaneously the decreased use of external keyboards, employees are more often suffering from discomfort in the back, shoulders and wrists. This is a result from awkward placement of the arm and back, necessary to use the laptop keyboard and mousepad. On top of that the head is tilted forward because the screen is not at eye height.[xv] The risk of mouse use also exists of two other factors, namely the applied forces to the mouse and how often it is used. These can both be estimated by using a force-sensing mouse.[xvi]

Too much tension on the postural muscles can cause injuries, and therefore the muscle activity needs to be monitored.[xi] Electromyography (EMG), which measures the electrical activity of the muscles, can help by indicating muscle fatigue and tension.[iv] With surface electromyography (sEMG), electrodes can be placed on the skin and amplitudes above a

certain predetermined threshold can be recorded. A considerable drawback of using EMG in research, is that there are always huge fluctuations in the participants' signals.[xi]
EMG can be used to examine the ill-effects of mouse use, by looking at the difference in muscle activity of the upper trapezius muscle at both the mouse- and the non-mouse side. This activity can be evaluated in three different ways.[xvii] The first is the amplitude probability distribution function, which can give an idea on the overall muscle load in periods of strain. $P = 0$ is the minimal contraction which occurred during the whole period of work and is called the 'static contraction'. $P = 1$, on the other hand, shows the maximal level of contraction and $P = 0.5$ gives us the median of the contraction.[xviii] The EMG results need to be normalized by using reference contractions to be able to draw conclusions. The EMG outcomes can for example be written as %MVC, which is the percentage of the maximal voluntary isometric contraction. This %MVC is measured with standardized measurement techniques for all the different muscle groups. For example, when looking at muscle activity of the wrist, the handgrip method could be used. The maximum activity is measured during muscle contraction, which occurs when a participant firmly squeezes a handgrip. The maximum activity of the muscles during this MVC, is called the maximal voluntary electrical activity (MVE).[xix] When looking at muscle load during activities as mouse use, the EMG results should not exceed a certain threshold, given in %MVE, which differ per muscle group.[xviii] The second method is the EMG gap analysis, which looks at the periods where the EMG level is below 0.5% of the maximum EMG amplitude for at least 0.2 seconds. Jensen and colleagues have shown in their research that the amount of EMG gaps was much lower at the mouse side than on the non-mouse side of the trapezius muscle. This is consistent with previous research which suggests that, when the amount of EMG gaps is low, muscles could get overloaded and MSDs can develop. Jensen et al. also used another analysis method, namely the exposure variation analysis (EVA). In EVA, different levels of EMG amplitudes and different lengths of time periods are predetermined. The variations in muscle activity recorded on the EMG are then allocated to these different levels. The results of EVA, which showed that the overall period of low muscle activity was much lower on the mouse side, are in agreement with their gap analysis results. All things considered, the upper trapezius muscle had longer periods of activity on the mouse side, probably due to the repetitive movements made when the mouse is used. EVA is seen as the most promising method for indicating risk factors of MSDs, but further research is needed to fine-tune this method or even to find a better method.[xvii]

For measuring the stress level of office workers, other techniques are required. The psychological burden of stress has been connected to changes in heart rate variability (HRV), which is the variation in time between two subsequent heart beats. More specifically, the time between to R peaks in an electrocardiogram (ECG). For an ECG recording, electrodes need to be placed on the office workers body, which could make it bothersome. However, luckily less invasive methods are being found to for example record a one-lead ECG with the help of smartwatches.[xx] HRV is determined based on different parameters like low frequency (LF), showing sympathetic activity, and high frequency (HF), showing parasympathetic activity. Hjortskov and colleagues found a significant decrease in the HF component of the HRV and significant increase in the LF/HF ratio during stress situations. This could indicate that especially the HF component of HRV could be a signal of stress.[xxi]

Ideally, systems include sensing techniques for both sedentary lifestyle and heart rate. This way, they could possibly prevent not only physical but also psychological strain. Besides that, it would be favorable if this measurement technique is as unobtrusive as possible for the office workers. Ren and colleagues have made a pad consisting of two sensors, suitable for an office chair. It can measure the heart rate via polyvinylidene fluoride (PVDF) film sensors, which quantify the HRV via vibration, originating in heartbeats. Additionally, it can measure the sitting durations and posture of office workers via force sensing resistors (FCRs). These sensors have not yet been tested in real office environments, which means that the outcomes could change there.[xxii] Further research needs to be conducted on the ideal sensor which can measure the risk factors of musculoskeletal disorders.

2 Problem definition

Office workers often suffer musculoskeletal disorders. They can lead to chronic and temporary pain, and therefore need to be taken very seriously. The problem underneath can be poor ergonomics in the office environment, which includes awkward postures and long sedentary periods. Employees do not take enough breaks from being seated and make the same movements over and over while using the computer for more than four hours. High demand and lack of autonomy at the office enlarge stress conditions and are known as psychosocial risk factors. Next to these work-related risks, also non-professional risks as age and sex can lie at the origin of MSDs. Most of the time, development of MSD is a combination of all the risk factors above. The problem is that employees are not aware of the fact that they are developing MSDs because of the hazards they face at the office. As there are multiple stakeholders (table 1) who are affected by the occurrence of MSDs among office workers, research needs to be conducted on prevention methods. Sensors placed in the office or on the employees' body are currently regarded as a possible solution.

2.1 Stakeholder analysis

It is very important to find out who your most important stakeholders are. They need to be engaged in the process as they can have a lot of influence on the project and can ultimately cooperate or counteract in reaching success.[xxiii] A stakeholder analysis is conducted to find out which main parties are involved in the problems caused by musculoskeletal disorders and in the process of finding the solution. Subsequently, there is explored in what way they are involved and what their expectations are. Obviously, there are potentials, but there are also shortcomings. These are investigated along with their implications and conclusions for the project. A summary of these results can be found in table 1.

First and foremost, office workers are affected by musculoskeletal disorders. They can experience short-term pain, which can even become chronic pain. This affects the working life of the office worker and can ultimately cause emotional problems.[vii] When an office worker also experiences the pain at home, it can hinder him or her in her personal life. Possibly the office worker is prevented from doing their household chores. Besides that, the emotional problems can lead to the office workers being unhappy and they can end up taking that feeling with them to their homes.

Table 1. Stakeholder analysis. The most important stakeholders are stated along with their characteristics. Their expectations with the potentials and shortcomings are given, as well as the final implications and conclusions to the project.

Stakeholders	Characteristics	Expectations	Potentials and shortcomings	Implications and conclusions
Office workers	Short- and longtime pain causing physical and emotional problems	Less occurrence of MSDs and thus less physical and emotional problems	There are many different MSDs and also many different (personal) risk factors which in combination lead to MSDs.	The product will hopefully increase their quality of life by decreasing MSDs occurrence
Family of office workers	Home life could deteriorate due to physical and emotional problems	Reduced physical and emotional problems and thus better mood at home	Can emotionally support office workers to decrease stress	Can report about the benefits at home gained from less MSD occurrence
Employers of office workers/company	Direct and indirect costs due to less productivity, lost work days or even permanent loss of employees	Higher productivity of their employees and thus less costs	The product should not hinder employees while working and should not be too expensive	Need to be convinced about the benefits this product will give them
Clients of office workers	Product or service delivered by office worker is substandard	To be satisfied with the product or service delivered by office worker	Would not want to pay for this product indirectly	Can report about the quality of the product or service delivered
Healthcare insurer	Higher costs due to payment of insurance to those affected by MSD	Less costs since occurrence of MSD decreases	Might not immediately see the benefits from the product	Are only going to be interested if the product is really efficient
Industry	Might gain money when they find a solution to the MSD problem	Earning money by developing an innovative product	Can take the product to the market, but only if it is beneficial	Have the knowledge on the market demand

Whenever musculoskeletal disorders get really serious, office workers tend to take sick days. They will then loose workdays, which decreases their productivity.[xxiv] But even when they do not take sick days, the pain can give rise to indirect costs, as the office workers cannot work at their full capacity. This is called presenteeism.[ii] In the worst case, when the office workers are permanently disabled by their MSDs, the company will get the costs of hiring and training new personnel.[xxv] Not only the company, but also the clients of the office workers can become affected by their presenteeism. When the MSD causes them to work less effectively and thoroughly, they will deliver substandard work. Clients are clearly disadvantaged in that case.

Lastly, the healthcare insurers are adversely affected by high occurrence of MSDs, since it will mean that they have to pay out more insurance money. The biomedical industry is engaged in the project as they are trying to find solutions to the problems arising due to musculoskeletal disorders. If they find a solution, they could earn a lot of money. As all the stakeholders, stated above, benefit from pain free office workers, they will probably invest in a product which can prevent MSDs.

All problems arising for the different stakeholders are in some way related to each other. These problems are shown by means of a cause-effect diagram in figure 1.

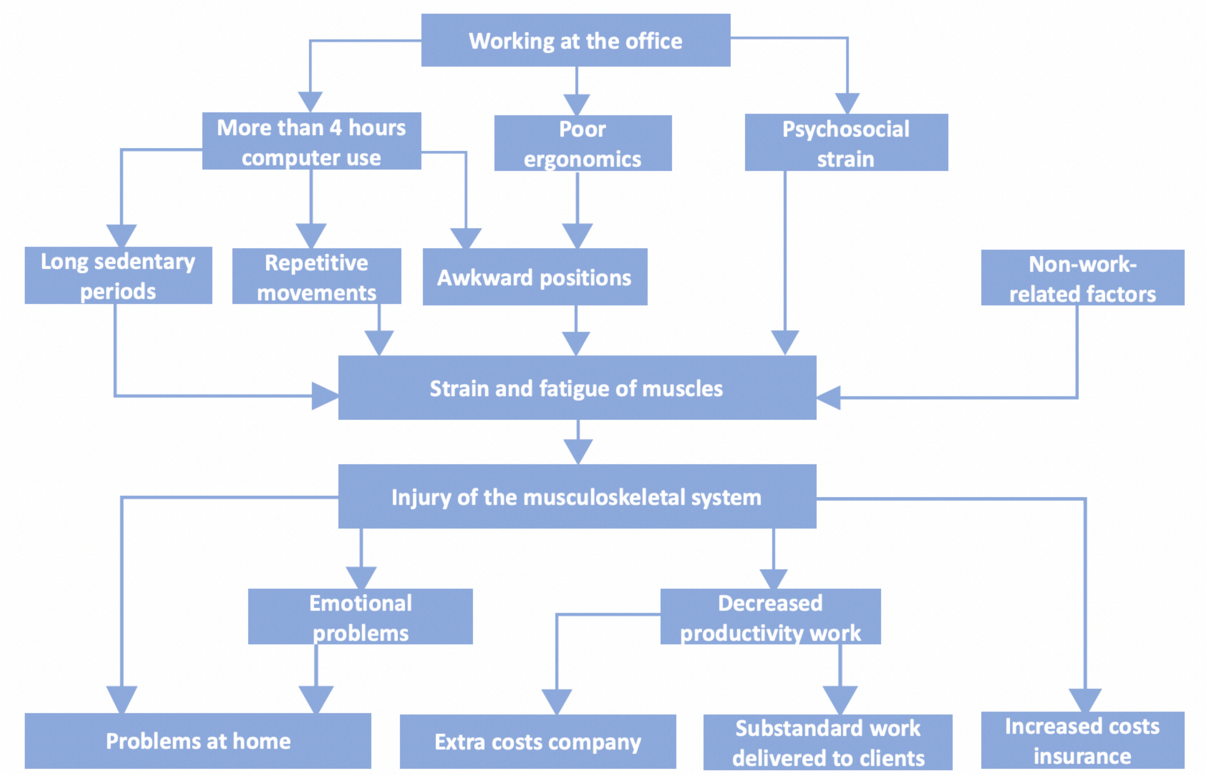

Figure 1. Cause-effect diagram. Starting with the main cause, namely working at the office, at the top. Then going down towards the negative effects that can arise because of that.

3 Goal description

The aim of the product that is going to be designed, is to measure the different risk factors of musculoskeletal disorders. At the same time, it needs to be minimally invasive. Hopefully, someday it can be used to prevent the development of MSDs among office workers. Even though employees keep working at the office, the sensors will help to protect them from hazards that exist in that environment. Ultimately, this will lead to less injuries of the musculoskeletal system and subsequently to higher productivity of the office workers. The other stakeholders also benefit from this outcome.

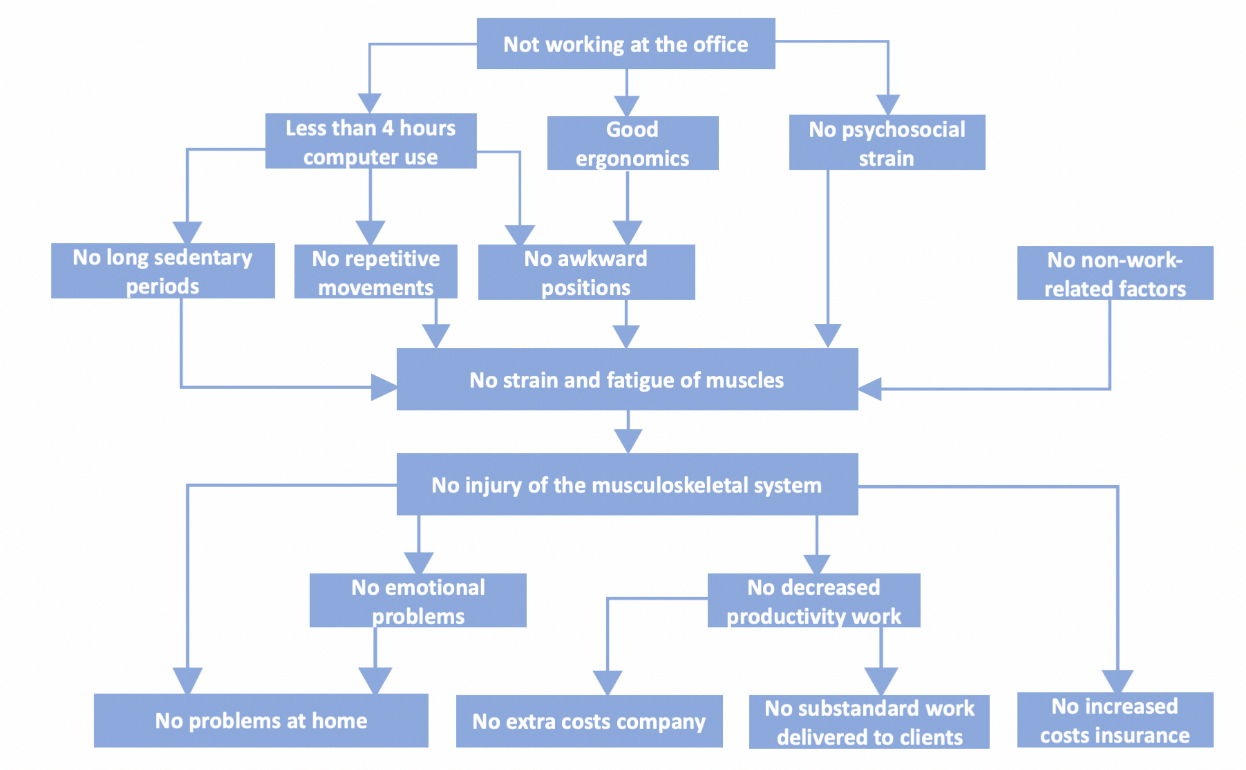

Figure 2. Cause-effect diagram. Starting with the fact that there are sensors at the office measuring risk factors of MSDs. Less development of MSDs among office workers will lead to positive effects for a lot of stakeholders, shown at the bottom.

4 Design assignment

The ultimate goal of this project is to realize a set of sensors which can measure risk factors of musculoskeletal disorders. To reach this goal, firstly extensive literature research has to be conducted to identify the risk factors of MSD at the office. Secondly, there needs to be determined which sensors are available to test and which risk factors can be measured by these sensors. The next step is to test the sensors according to the requirements and wishes of this product. As the sensor someday needs to be used at the office, it may not hinder employees. If the productivity of office workers would decrease because of the sensors, the sensors would defeat their purpose. Therefore, in this project there will be investigated which sensors can measure the risks correctly while complying with the requirements and wishes of the product.

4.1 Demarcations

The main limitation is that the project only takes 10 weeks. This means that there is not enough time to deliver a full report on which sensors would be best to use in the office environment. Since many sensors have a long delivery time, it is not even possible to test all the desired sensors. Therefore, it needs to be determined up front which risk factors need to be measured by the sensors. Because there are always several factors contributing to the development of MSDs, it is not possible to link the measurable risk factors to MSD development with certainty. For example, the sex of the test person could bias the results. On top of that, only data from one individual will be used, as the pandemic situation does not allow us to set up a proper trial with multiple participants. The results will therefore probably not be significant. On top of that, actually surveys would need to be handed out simultaneously to be able to make a connection between risk factors and MSD development. All in all, it will only be possible to test the ability of the sensors, but it will not be possible to directly link it to the development of MSDs. Besides that, sensors cannot be tested simultaneously. Ideally, there would be a sensor unit which can measure many risk factors at the same time, but in this research, it will only be possible to test the sensors individually.

Aside from the measuring units, data acquisition equipment is also needed. The recorded data needs to be transmitted, stored and displayed at for example a smartphone or computer. Bluetooth could be used to transfer the results to a display monitor.[xiv,xvi] Sometimes signals are electric and need to be amplified before they can enter the data acquisition unit.[xxvi] Microcontrollers and energy sources are needed to enable that. Unfortunately, the short time span of this project makes it impossible to investigate these things. Therefore, future students should look into the steps of the data processing and storing and the possible energy sources.

5 List of requirements

The sensors are used to prevent the development of musculoskeletal disorders. The decrease in MSDs will then, among other things, lead to increased productivity of office workers. A sensor which would disturb employees while working, would decrease this productivity again. Therefore, it is important that the sensors are as unobtrusive as possible. Besides that, there are many other requirements. Sensors can either be wearables or non-wearables. As wearables are worn on the body and non-wearables are for example installed in a mat for the office chair, these subgroups have different requirements. Firstly, the general requirements are determined. Secondly, the specific requirements for both the wearables and non-wearables are written down. These requirements are divided with the help of the MoSCoW method. Whenever a requirement is categorized as (M), it means that it is a Must have requirement. When this requirement is not met, the product will definitely have failed. The label (S), means that the product Should actually meet a requirement. However, it is not disastrous if it is not possible to meet this requirement, because possibly there is an alternative way to reach the same goal. (C) shows that the product Could have this specification. It is a wish rather than a requirement. Won't have (W) means that no time will be spent on trying to meet a certain requirement. Basically, there is not enough time to fulfill all requirements and wishes and therefore the (W) requirements should not be given any time.[xxvii]

5.1 General requirements

Utilization requirements

- Sensor fulfills the ISO standards. (M)
- Sensor must allow data transmission to a personal computer using standard serial protocols. (M)
- Sensor must be cleanable within 10 minutes. (S)
- Sensor can be reused. (C)
- Sensor is not felt by the office worker. (C)
- Sensor unit can measure multiple risk factors at the same time. (C)
- Sensor can give feedback signals. (C)
- Sensor looks appealing. (C)

Ergonomic requirements

- Cables from the sensor do not hinder employees in their motion, maintaining good ROM. (M)
- Sensor itself does not hinder employees in their motion, maintaining good ROM in work environment. (M)
- Sensor does not restrain office worker from performing tasks. (S)
- Sensor does not influence the sitting position. (S)
- Sensor is described as comfortable in 90 out of 100 office workers. (C)

Safety requirements

- Sensor does not get overheated. (M)
- Sensor does not have sharp edges. (M)
- Sensor does not interfere with other electronical devices on the body. (M)
- Sensor does not harm any part of the body. (M)
- Sensor does not worse MSD symptoms. (M)

Material requirements

- Material does not cause long lasting irritation of the skin (longer than 30 min after removal sensor). (S)
- Sensor is sustainable. (C)

Financial requirements

- Sensor does not cost more than 500 euros. (S)
- Sensor should last at least 5 years. (S)

5.2 Wearables

Utilization requirements

- The sensor can be worn in combination with office clothes. (S)
- Office workers can put the sensor on their selves. (S)
- Product does not weigh more than 500 grams. (S)
- Sensor can be put on in 5 minutes. (C)
- Sensor does not show through clothes. (C)

Ergonomic requirements

- Sensor itself does not hinder employees in their motion, maintaining good ROM in personal environment. (S)
- Sensor is as small as possible. (C)

Safety requirements

- Application and removal of sensor does not cause any pain. (M)

Material requirements

- Sensor is completely waterproof. (M)

5.3 Non-wearables

Utilization requirements

- Sensor fits on all office chairs and tables. (M)
- It is easy to get used to using the sensor on e.g. a mouse. (S)
- Sensor can handle small hits by e.g. an arm. (S)
- Sensor is installed within 5 minutes. (C)

Ergonomic requirements

- Sensor can handle body weight up to 220 kg. (M)

Material requirements

- Sensor is splash proof. (M)
- Sensor is completely waterproof. (C)

6 Function analysis

The sensor must detect clinical relevant changes in the behavioral and environmental variables that have been identified as risk factors. Therefore, the main function of the sensor is to transport information and ultimately store it such that the information can be evaluated via a computer program. In addition, energy must be stored and transported into the sensor to allow it to work. This is showed in a block scheme in figure 3.

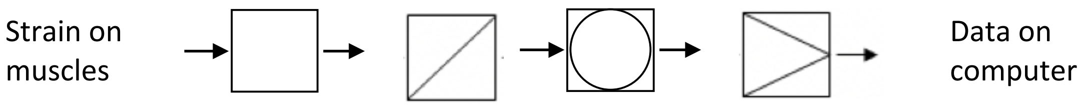

Figure 3. Function block scheme. Starts with strain on the muscles and ends up with data on a computer.

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