B.Sc THESIS

Real-time Posture Improvement for Squats.

Designing a wearable that improves posture during a squat by providing haptic feedback.

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Abstract

Many people do sports as hobby or to stay healthy; individual or in a team, outside or inside, there are many different possibilities and sport associations. One sport that is becoming increasingly more popular is working out. Many people go to a gym, have equipment at home to work out or follow a workout video on YouTube. The squat is an important exercise during many workouts, it is a rather simple and universal exercise that can be performed without any equipment. For the squat to be effective it needs to be performed with correct posture. If this is not the case muscle growth will be limited and there is an increased possibility for injuries. A good way to assure that the squat is done correctly is to have a trainer check the performance, but not everybody has a trainer available. Especially if a video is followed or people workout at home.

To not replace a trainer but help those who have no trainer available a wearable is created. This wearable will track the movement of the user during the squat and check the posture. If posture is not correct during the squat it will give feedback about how to change the posture so it can be improved in the next repetition. The feedback is real-time, this means that the feedback is given during the exercise and not after a set of squats is done. The posture is measured by two IMUs, Inertia Measurement Unit, one placed on the lower back and another on the front of the knee. Vibration motors are used to give this feedback, a vibration motor is placed on the lower back and at the side of the knee. The side of the knee has a set of three vibration motors that together create a haptic pattern that indicates direction. The sensors and vibration motors are integrated into a wearable that consists of two parts; a band around the waist and a band around the knee. The band around the waist also contains the micro controller, an Arduino Nano, that filters the incoming data and contains the code to check if a squat is performed correctly.

The wearable has been tested with a user test, six participants participated in qualitative research about the wearable. The participants used the wearable and answered a questionnaire before and after the test. The tests were performed to check if the set requirements were matched, find points of improvement and find possibilities for the future. The overall impression of the user-tests is that the participants saw the potential that the wearable has, but further development is needed. Especially the accuracy of measuring posture and the haptic patterns need more development.

Contents

List of Figures

List of Tables

1 Introduction

Working out is becoming increasingly popular, not only have subscriptions to gyms increased massively over recent years [1], but a good fitness account on YouTube like THENX can have up to 7 million subscribers with more than 70 million views of top videos [2]. Many accounts exist that guide viewers through a home-workout. Most of the presented exercises by these accounts require no to little equipment which makes them accessible to all viewers. One widely presented exercise in these videos that requires no equipment is the squat. A simple exercise primarily aimed at training quadriceps [3]. It is performed by bringing the hips down until they are parallel to the floor while maintaining the centre of mass over the middle of the foot [4].

A problem arises when 70 million people follow these online workouts without a trainer present. So nobody is checking up on the execution of the squat, this may result in a poor execution of the squat. Proper execution will increase the effectiveness, thus improves muscle build, flexibility and mobility, preventing injuries at the same time [5]. In addition to these advantages of performing a proper squat a study by M. Vanderka et al. [6] shows that modern day training of professional athletes is making use of instant feedback; the study conclude that instant feedback improves the performance of an athlete and thus improves muscle growth [6].

Instant feedback for athletes is already widely implemented in sports like running and cycling [7]. Watches equipped will various types of sensors track the action of the athlete and give live feedback on speed, heart rate, distance etc. A wearable that can measure the posture during the squat and give real-time feedback to the user would improve the execution of training exercises at home. A smartwatch is of course a wearable but lacks in its ability to provide feedback on posture. To properly provide feedback on posture a new wearable needs to be created. This thesis will set out to find an intuitive implementation and design of such a wearable by following user-based research in which testing is important to make small iterations to improve implementation. Due to COVID-19 this testing will mostly be performed on the researcher himself or close relations.

1.1 Research questions

The main research question in this thesis is:

How to design a wearable that improves posture during the squat by providing haptic feedback?

Seven sub research questions answered in this thesis are:

a. Where is haptic feedback used in sport movements?

b. How can the correct execution of the exercise be measured?

c. What is a proper way to give the user understandable haptic feedback?

d. How can data be retrieved from the sensor and properly filtered?

e. How is a correct squat identified using the data?

f. What is useful and understandable feedback?

g. Where and how are the sensors and actuators placed on the body?

1.2 Structure of the paper

This thesis contains all necessary information required for designing a wearable that is able to improve posture during a squat using haptic feedback. Each chapter contains a function and a goal. Chapter 2 presents a background study based on existing literature, current state of the art and an expert interview. Literature and state of the art were used to understand which aspects are important during the design process. The expert interview provided insights in the way how a trainer would give feedback during the squat, this helps in designing the kind of feedback that needs to be given. All background research together yields a rough initial design that can be used to futher build upon.

The method for conducting the interview and the method for fast iteration research are discussed in chapter 3. The method for conducting user-tests is presented as well. The initial idea is discussed in chapter 4.1, the user group is explored as well by analysing different user scenarios and conducting a stakeholder analysis. This analysis is used to take a critical look at the initial idea and to identify the requirements for the wearable.

Chapter 5 specifies the needed components and discusses how these components are to be used. These specification are used for the realisation of the wearable, this process is presented in chapter 6. The wearable created in Chapter 6 is evaluated in Chapter 7 by discussing the outcome of the user tests. The outcome is discussed in Chapter 8, leaving Chapter 9 for drawing conclusions and for giving recommendations.

2 Background research

Background research is conducted to be able to design a concept that is grounded on theory. To arrive at a grounded concept different aspects are being discussed. As a start a literature review is carried out into the optimal positioning of the wearable and into feedback patterns. This study includes research papers in which earlier similar research is presented, the papers are reviewed and the parts that are relevant for this thesis are discussed. In addition a state of the art of products that have a similar goal as the wearable will be investigated. This will provide insight into existing products, this knowledge can be used to improve the grounded concept found in the literature review. Finally the requirements for the sensors and microcontroller will be discussed and options will be presented. This is important because it allows to review the grounded concept for feasibility. Together this will provide a reviewed grounded concept on which form a basis for the remainder of the thesis. In the process of finding a grounded concept this chapter will answer three sub-research questions: Where is haptic feedback used in sport movements? How can the correct execution of the exercise be measured? What is a proper way to give the user understandable feedback?

2.1 Literature review

The literature review has two parts; the first sets out to find an effective positioning of a wearable for the squat. More knowledge into positioning is needed to assure that the wearable is functional and measures correctly. The aim of the first part is therefore to find the optimal position and rate of measurement. The second part of the literature review sets out to find patterns that will give the user positive or constructive feedback that is noticed even under a high cognitive load [8]. Such patterns are important because a workout requires a lot of energy and therefore already gives a high cognitive load. These patterns are identified by reviewing papers in which the use of haptic feedback in sports is presented. Not only the squat will be reviewed, but all types of sports in which haptic feedback is used will be included. Section 2.1.1 of this paper will set out to find the optimal positioning , section 2.1.2 will discuss feedback patterns for the wearable and the implementation of this knowledge into the grounded concept is discussed in the conclusion.

2.1.1 Good positioning

To find the correct positioning of the wearable three aspects need to be taken into account. First the correct squat form needs to be reviewed to assure that sensors are placed in vital positions. After that the placement of the wearable itself is discussed. Finally the rate of measurement will be reviewed.

Squat position

When a squat is performed it is important that this is done with good form. A good form will assure that the exercise is more effective and therefore improves muscle build, flexibility and mobility, it will also prevent injuries [5]. One catch can be found in an article by Everett [9] and in an article by Somerset [10], both state that executing the squat in perfect form is related to individuals, the uniqueness of people makes that the perfect squat differs per individual. Everett [9] states that this is caused by personal anatomical peculiarities, each hip and knee joint is different and has different degrees of freedom. The consequence is that everyone can squat to a different depth and has a different optimal angle of the feet pointing outwards [9]. This raises the question of how a universal sensor can be used on multiple people.

Even though everyone can squat to a different depth the article by Finn [3] considers research by Dr Rafeal Escamilla, professor at California State University, who reviewed over 70 papers on knee bio-mechanics during the squat and concluded that even though someone can squat beyond 90°, 90° is enough to achieve very high levels of muscular activity and thereby train the quadriceps [3]. The same article states that knee joints should not be a limiting factor for maximal squat depth. Instead of knee joints one should look at the lower spine. Because when a squat is performed well the spine has a natural arch. When this natural arch is going to a rounded spine because the squat is badly executed great pressure is put on the discs in the spine, which is likely to cause injury [3].

Another aspect that is equal for everybody who performs the squat is the centre of mass. In the article by Dr. A Horschig and Dr. K Sonthana [4] the myth that during the squat the knees should not go over the toes is debunked. It is stated that knees first is the wrong way to start a squat. It is also stated that bowing the knees is used to adjust the centre of mass, keeping control over the centre of mass is important in the squat. Knees not going over the toes is a way to assure that hips are moved first, but more importantly is the centre of mass above the middle of the foot. Figure 1 shows the perfect squat, this figure also shows the muscles that are used during the squat.

Placement

After reviewing a good squat position the placement of the wearable becomes important. To explore this placement, literature is reviewed that focuses on wearables using haptic feedback. In a review of wearable systems for sports [12] it is discussed that placement on the body should be logical. An important factor in this is cultural acceptance, this means that it is culturally accepted to wear a device in that place. This results in most haptic devices being wrist-worn, it is culturally accepted to wear a watch on the wrist and therefore the transition to a haptic device is easier in that position. Although the wrist is the most used option for a wearable, other options are reviewed as well and these do not show dysfunction. The paper by C. Militaru et al. [13] states that key body joints, like knee, hip, ankle and lower back should be checked to analyse the squat correctly.

Measurement

The rate of measurement is related to correct positioning of the sensors. If the positioning is wrong no measurements can be taken but a faulty rate of measurement makes optimal positioning useless. When

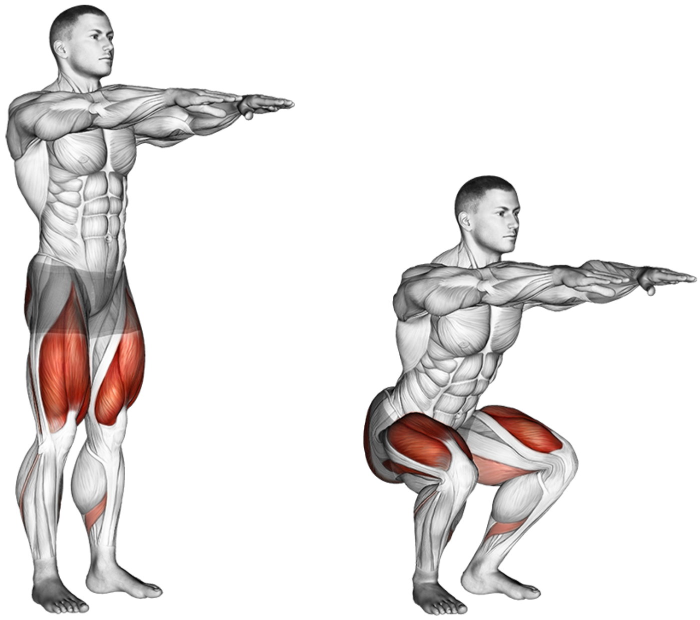


Figure 1: Execution of a perfect body weight squat [11].

performing an exercise instant feedback can boost the performance significantly. Modern training by professional athletes therefore includes this type of training [6]. The squat is a rather quick exercise, this means that a wearable needs to process data quickly to be able to give feedback every single movement. Even if it is possible to process every movement, received triggers and response time are an issue. In haptic feedback between 70-100% of the triggers is actually received by the user [14], combining this with an average response time of 1.5 seconds [14] makes it impossible to measure every single repetition. Fortunately this is not necessary, in an application that reviews squat using visuals, feedback is only given once every eight seconds [13]. This is supported by Foster [14] who states that triggers are perceived better when there is more time in between the triggers.

Combining the information from the studied papers on positioning it would make sense to separate feedback and micro-controller. This means that feedback can be given at the location the user needs to adjust posture while the micro controller can be stored in a convenient place which does not interfere with the execution of the exercise. The reviewed rate of measurement papers conlcude that when measuring the squat exercise it is not necessary to give feedback on every single repetition but every two or three would be sufficient.

2.1.2 Feedback patterns

After the wearable is placed in an optimal position, separating microcontroller, sensors and feedback while providing feedback once every two or three executions, the kind of feedback becomes important. The received data will be processed by a micro controller and then given back to the user in the form of feedback. Feedback can be given in different ways. Three often used ways are haptic, visual and auditory feedback [15]. Haptic feedback will be compared with visual and auditory feedback based on effectiveness for the squat, the comparison will be made by reviewing different papers regarding the three types of feedback. Besides the type of feedback other aspects of haptic feedback will be discussed, including: cognitive load, haptic illusion, number of actuators and frequency.

Haptic, visual and auditory are three widely used ways to give feedback to the user. Haptic feedback uses touch to provide feedback, visual feedback is feedback that is received by the eyes, auditory feedback uses sound to provide feedback. An example for haptic feedback is the mobile phone that vibrates when a message is received, for visual feedback even a traffic light can be considered and a beeping smoke detector is a good example of auditory feedback. Comparison of these three ways of giving feedback shows that visual feedback has the highest correct response on triggers, followed by haptic feedback [14]. The paper by Sigrist et al. however states that haptic feedback is the only one that allows to maintain outside interaction [15]. Outside interaction is extremely important because it allows the user to keep watching the video trainer while receiving feedback. Furthermore it states that simple tasks are effective with haptic feedback and increases effectiveness of the haptic feedback, regarding the squat this is a good combination [15]. Sigrist et al. also mentions a downside of haptics. It cannot be used to teach the user a whole new movement. Fortunately the goal of the wearable is to adjust posture and not learning an entire new movement.

For the wearable to provide useful feedback it needs to be assured that the feedback can be perceived by the athlete under a high cognitive load [8]. Reviewing the advantages of haptic feedback stated by Sigrist et al. [15] shows that outside interaction is possible. This suggest that the user is capable of watching a fitness video while receiving feedback on the exercise. This results in the suggestion that haptic feedback has low cognitive load. This is supported by a paper by Spelmezan [8] and Kosmalla et al. [16] in which high cognitive sports are performed, snowboarding and climbing. These papers show that even in these high cognitive sports the haptic feedback is perceived and understood. This assures that also under tiredness of performing the squat, the haptic feedback will still be processed by the user.

There are two options forgiving the necessary haptic feedback , a plain vibration or a haptic illusion. A haptic pattern is using vibration to create a certain pattern or feeling that can be linked to a direction or action. The advantages of haptic illusion are that it can portray the required movement so recognition of the required movement is easier and that it can create a realistic touch sensation [17]. A paper by Stock et al. [18] sets out to use haptic illusion to navigate, it uses four vibration motors to portray direction. Controlling the rate of vibration enables exact recognition of locations instead of just north, east, south and west. The paper by Heo and Lee [19] changes the vibration to a haptic illusion when using mobile phone to indicate the kind of message the user receives. So using haptic illusions might help the user in recognizing the movement that needs to be performed when feedback is given. Han et al. [20] states that users can recognize 6 different patterns with an accuracy of 91% [20]. Furthermore a paper by Israr [17] states that if two actuators are placed six centimeter apart and have overlapping vibration time, it will be perceived as one moving tactor. If the information from the papers is combined it creates a concept that can be tested in later phases. The concept is to create a moving pattern that is perceived as a direction to indicate the movement the user has to make in the squat.

There are some limitations to this haptic illusion, Israr [17] states that placing the actuators too close or with too much overlapping time will result in perceiving one big tactor. Also overuse of actuators will result in reduced effectiveness [17]. Furthermore the actuators need to be in the optimal settings to be perceived by the user, these settings are 80-500 Hz for the vibration and 200-300 Hz for resonance. The human operator is most sensitive for these frequencies and are therefore the optimum settings for haptic feedback.

2.1.3 Conclusion

A literature review has been performed to find an effective position for the wearable and clear patterns to provide the user with haptic feedback. It can be concluded from this literature review that effective positioning of the wearable is determined by the following factors: execution of the squat, key body joints, place of feedback and rate of measurement. Reviewing the aspects mentioned in the previous sentence results in a separation of micro controller, sensors and the actuators. The micro controller will be placed on the lower back as well as the sensors to measure back stability. Another sensor will be placed on one of either knees, comparing both sensors will allow for measuring whether the hips moved first. It will also measure the angle of the knee because it is good practice to not move knees over toes and it will help non-professionals to keep proper posture. The actuators will be placed at the same places as the sensors because these are the places that needs adjusting when performing a squat. Measurement will be made once every two executions to avoid a feedback overload while keeping an instant feedback factor. The rate of measurement will be tested in chapter 7 but the literature suggests once in two executions is a very good start.

In order to find a proper feedback patterns different kinds of feedback were reviewed, haptic, visual and auditory. A review of the state of the art and literature shows that haptic feedback will provide the low cognitive load this review set out to find. The literature review of feedback pattern also resulted in the use of haptic patterns to create low cognitive patterns with a high recognition factor. From this literature it can be concluded that haptic patterns that indicate direction of movement are going to be used to steer the user into adjusting into the right direction. For this implementation distance between the actuators, rate of vibration and resonance need to be taken into account to assure optimal perception for the user.

2.2 State of the art

Research into the state of the art showed that there are no existing products that measure the execution of the squat and provide real-time haptic feedback. Products, however, are available that have the same goal as the wearable or have similar parts as the wearable. These products are investigated to learn how they handle challenges that will be encountered in this graduation project.

2.2.1 Feedi

Feedi is a footband consisting of 1 IMU (inertia measurement unit) and 4 vibration motors [18]. The footband is a navigation wearable, so it uses the vibration motors to indicate the direction the user needs to take. This is done by placing the 4 vibration motors around the ankle. Precise directions are given by varying with the power of the vibrations, so if a user needs to go North-East-East the vibration motors of north and east will vibrate but the east motor will vibrate a bit stronger. The IMU is used to measure the direction the user actually goes and whether the user is walking or not. This is recorded by the gyroscope and accelerometer in the IMU, the gyroscope measures angle and the accelerometer measures acceleration. The Feedi footband is relevant because it combines the sensors and tactor that are used in this graduation project.

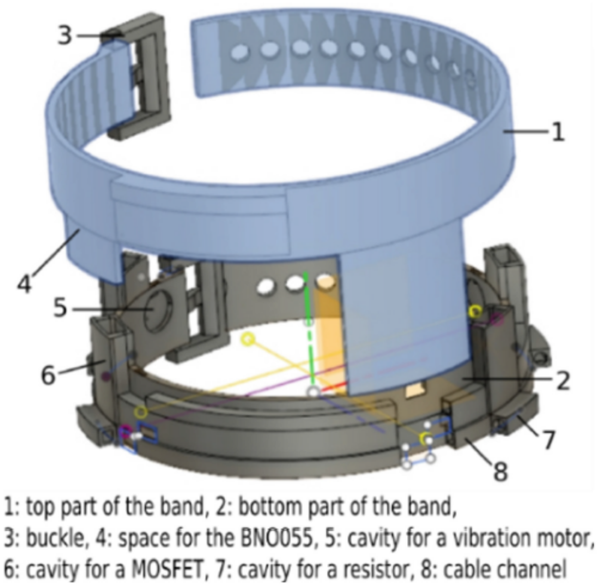


Figure 2: Feedi footband wearable.

2.2.2 Visual feedback during jump squat

This section is based on a paper by Vanderka et al. [6], in which a product is used that is not the market but which does implement the workings of a related product in research. The research compares a feedback group to a non-feedback group while performing the squat, the important aspect here is that the feedback group did receive real-time visual feedback based on an accelerometer placed at shoulder height. This accelerometer provided concentric power output of the user. The research did not measure the performance of the squat but measured the improvements of the athletes. The research showed that the group with feedback performed significantly better than the group without feedback. This research shows that even with only having output feedback the improvement increases over time.

2.2.3 Push

Push is a wearable that can be connected to an app [21]. The wearable is worn at the upper arm and for example measures velocity. Push is not only used for the squat but for many workout exercise that are usually performed in a gym. It measures how often a certain exercise is done which at the end of the workout gives the user a clear overview of the exercises done and the number of repetitions per exercise. When the squat is examined using Push it also measures squat velocity, i.e. how fast the user goes up or down in a squat. A paper by Balsalobre-Fernandez et al. [22] reviews this wearable regarding the squat and concludes that sensing velocity and repetitions is adequate but the amount of different aspects that are measured is rather limited. Very important is that this product does not deliver any real-time feedback.

Figure 3: Push wearable used during a weighted squat.

2.2.4 SquatScreen

SquatScreen is an application for professionals such as physiotherapists, it helps a professional to analyse the posture of the client during the squat. The professional can use such an analysis to improve the posture of the client. In this application the camera of tablet or phone is used to make a video of the squat, followed by an algorithm detecting key joints of the body and clarifying this by putting dots on them. The application gives instructions on how the dots should be aligned enabling the professional to easily detect any needed changes. An advantage is that the video can be sent or shown to the client enabling the client to detect him- or herself what is going wrong.

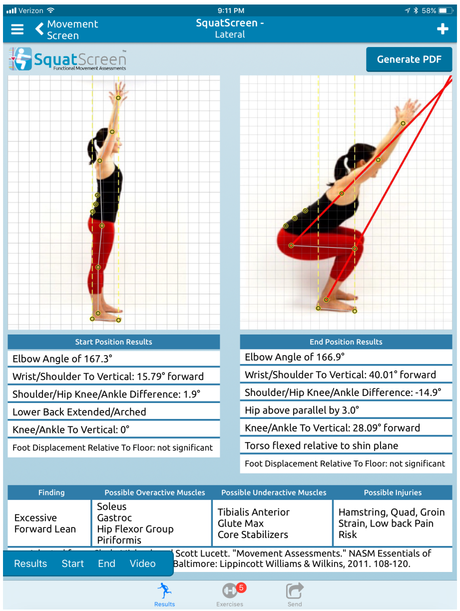


Figure 4: Contents of application of SquatScreen.

2.2.5 Vivoactive 4s

The idea of providing feedback during sports is not new, the best-known wearables are sport watches like Garmin [7]. Which usually gives visual feedback on running, biking, swimming etc. This visual feedback often includes heart rate, speed, distance and passed time. In these watches visual feedback really overshadows haptic feedback. The garmin Vivoactive 4s [23] uses haptic feedback for the alarm clock in the watch or to notify the user that an activity can be started but is not used as way of providing feedback during an activity.

Figure 5: Garmin vivoactive 4s

2.2.6 Conclusion

Analysis of the different already existing products, Feedi, Push, squatScreen and sports watches, together with analysis of the research using a feedback product results in the following conclusions. There is a clear gap in the market of wearables for wearables that provides real-time feedback without needing a complete set-up.It can also be concluded that such a wearable needs to be compact and should have no external interaction except for an application if this would be required. It can also be concluded that existing real-time feedback focuses on the result and feedback on the posture of the user is only given afterwards.

2.3 Expert interview

An expert interview was conducted to gain more insight into performing a squat. The structure and setup of the interview are given in section 3.1, the results of the interview are discussed below.

The expert explained about his checking pattern for the squat, basically going from toe to top. Starting at the bottom and then working his way up until everything had been checked. Checking of the feet involves three aspects, whether the feet are at shoulder width or slightly broader, whether the toes are turned about 30 degrees outward and whether the heels are on the floor. After checking the toes he moves up to the knees and seeing whether the knees are pointing outwards during the exercise, whether the knees do not go past the toes and whether the upper legs are parallel to the floor. A suggestion he always gave to his trainees is to pretend that there is a toilet behind. After the knees he moves up to the chest, the chest needs to come forward, as if they are really proud of themselves. Finally he checks whether the neck is in neutral position.

The expert then continued by explaining which muscles are trained, these are the quadriceps and to some extent the counter muscle. The expert also mentioned that even experienced squatters do not always perform the squat correctly, especially when they try a weighted squat and add more weight than what they are used to and pull up from their back and not from their quadriceps which can cause injury. Figure 1 shows a perfect execution of the squat.

The final question by the interviewer to the expert was whether he would consider the wearable valuable, the expert answered that he really does because he sees that the squat exercise is often performed incorrectly.

It can be concluded from this interview that knee, hip and back are important joints that should be the focus of posture correction. Another conclusion is that the feedback given by the trainer is directional or uses a trick to make the trainee move into a certain direction. This means that the feedback given by the wearable should do the same, it should give a hint on how the trainee can improve his/her posture.

2.4 Hardware

For the wearable to be effective the sensors and microcontroller need to meet certain requirements regarding measurement rates, measured variables, processing speed and input availability. If these requirements are not up to standard the wearable might be too slow which can result in feedback being given at the wrong time. A possible sensor and microcontroller will be proposed in this section.

2.4.1 Sensor

As stated in section 2.1.3 the sensors will have to be placed on the lower back and the knee. At the lower back position it will measure the angle of the back bone and whether the hips are moving before the knees move. The knee sensor will measure the angle of the knees to assure that the knees do not go over the toes. This sensor will also measure when the movement starts by comparing it with the hip sensor. Considering these requirements for the sensors an IMU is a suitable sensor. This consist of gyroscope and accelerometer [24]. The gyroscope measures deg/s, i.e. degrees turned per second along the x, y and z axis. The accelerometer measures g, 1 g is the gravitational constant, i.e. 9.81, also measured along the x, y and z axis. The IMU MPU-6050 is a good option with a large range of ±2000deg/s in the gyroscope and ±16g in the accelerometer.

2.4.2 Microcontroller

The microcontroller must meet three requirements, it needs to be able to handle at least two IMUs and control six vibration motors. It also needs to have enough computing power to execute the necessary code in a limited time span. The final requirement is that it does not restrict the user in any way, this means that the microcontroller needs to be as small as possible. These three requirements are met by the arduino nano. This has enough analog ports to read out IMUs and is able to control enough vibration motors [25]. It also has 30 kb of SRAM and a clock speed of 16 mHz which should be enough to execute the necessary code fast enough. The board is 18 x 45 mm and weighs 7 grammes making it very small and lightweight. All this makes the Arduino Nano a good choice as microcontroller.

2.5 Conclusion

The background research enables creation of a grounded initial design. The four parts of the background research each contributed to the initial design.

The literature review contributed largely to the initial design, the positioning of the sensors and vibration motors can be concluded from the review. Sensors should be placed on the lower back and knee, each measuring an individual parameter and also comparing data with the other sensor. The literature review also showed that the vibration motors needs to be placed around the knee and lower back in order to give feedback that is related to the position of the motors. The literature review also showed that feedback patterns can be used to clarify feedback. Combining this with the findings from the expert interview, that most spoken feedback by an expert is directional, gives a plan for the feedback. Two vibration motors will be placed at the knee (or lower back), these vibration motors will be programmed in such a way that they give a directional feedback pattern that indicates the direction of how posture needs to be corrected. Finally the literature review showed that providing feedback every repetition will overload the user, this is why feedback needs to be given only once every two repetitions.

It can be concluded from the state of the art that the real-time aspect of providing feedback is very important. According to current knowledge no devices exist that combines real-time feedback on posture with low-cognitive load feedback.

Finally the research on hardware delivered an IMU and microcontroller capable of measuring and detecting how a squat is performed with the ability to control enough vibration motors. The microcontroller needs to be as small as possible to assure that it does not hinder the user.

3 Methods and techniques

The methods and techniques used in this graduation project are explained in this chapter. This will be done in three different sections relating to three different phases of the graduation project. First it will discuss the method for the conducting the interview of which the results are presented in section 2.3. Second the way in which iterations during the design process are made, especially in relation to the covid-19 pandemic will be described. Finally a setup for the final testing phase in which user-tests are performed will be discussed.

3.1 Interview

A semi-structured interview was conducted to gain more understanding of the interaction between a trainer and a trainee during the execution of the squat. For which an expert on physical training was interviewed. The interview had two objectives: a. acquiring information on how a squat is performed and b. how feedback is given during training sessions. Because the interview was intented to gain information about these aspects. The semi-structured interview was chosen because this allowed for an in-depth interview about the chosen topics. The full guideline of the interview, brochure and informed consent of this interview are given in Appendix A.1 and A.2.

3.2 Iteration

During the design process a lot of iterations will be made. These iterations are performed according to the engineering design process. A visualization of this process is shown in figure 6.

Examination of design process show that for the first iteration the parts ask until plan are done in chapter 2. After a prototype is created this needs to be tested, this will be done initial experiments on the researcher. The goal of these experiments is to find a setting that can be used as base setting. These settings will later be tested in the user-tests. In the graduation project this will result in testing iteration on the researcher himself until a standard is reached that self-testing is no longer adequate or more elaborate testing needs to be done.

The selection of this type of research has two reasons. First it benefits the research process if the iterations can be done quickly, this results in more iterations which will help in delivering a good end project. The second reason is that this research is conducted during the covid-19 pandemic.

3.3 Testing

In the last phase of the graduation project the wearable needs to undergo a user test. In which the wearable will be tested by different people so the researcher can gain more knowledge about the overall interpretation of the feedback and if the wearable is user friendly. The findings of this user test can be

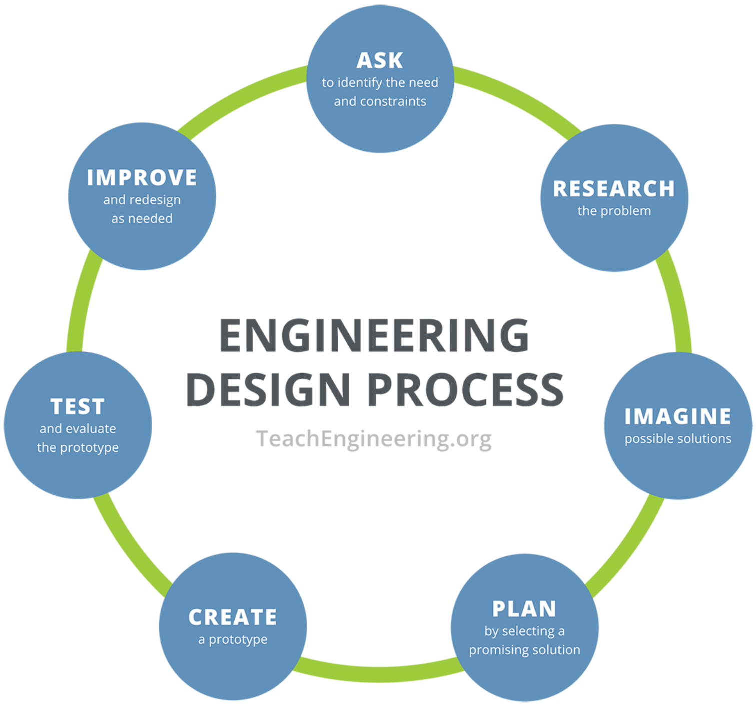


Figure 6: Engineering design process [26]

used to make further recommendations for the development of the wearable. The complete setup of this user-test can be found in chapter 7.

4 Ideation

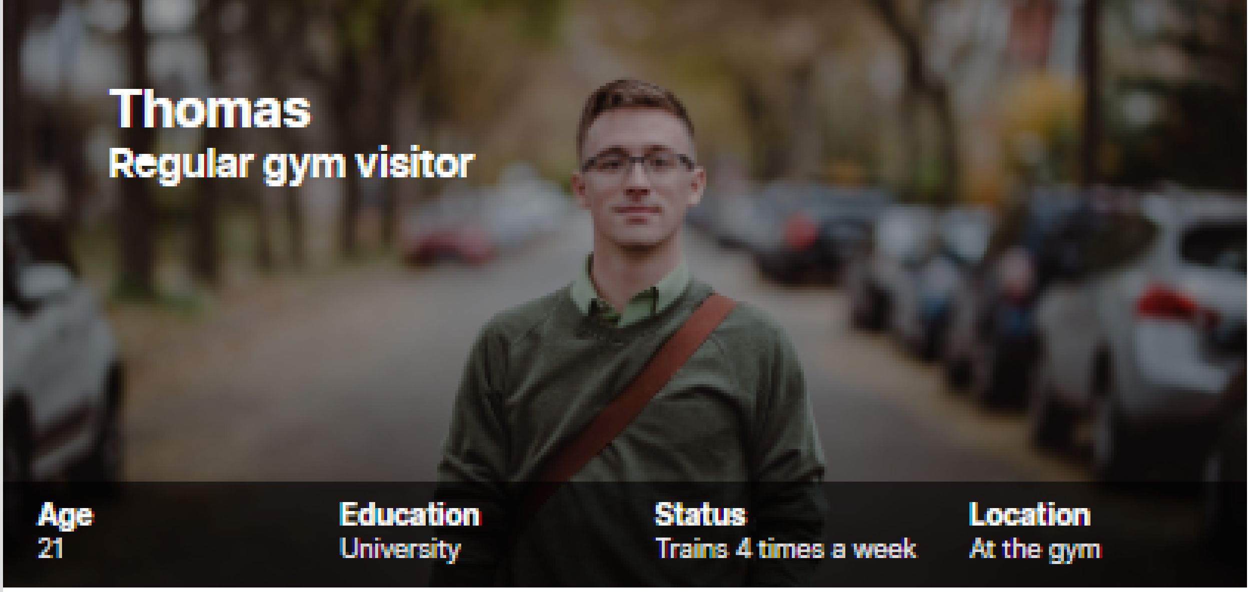
The ideation of the project will be presented in this chapter, starting by discussing the initial idea that is based on the research done in chapter 2. The initial idea is followed by four user scenario's that will provide a deeper understanding of how the users will interact with the wearable and of their goal of using the wearable. Finally a stakeholder analysis is conducted to find relevant stakeholders and the barriers and opportunities these stakeholders provide.

4.1 Initial idea

The initial idea is to attach one IMU to the inside of the knee, this IMU will measure how far the knee goes outwards as well as the moment on which the movement in the knee starts. The second IMU will be attached to the lower back, this will measure the angle that the backbone makes as well as the moment at which the movement in the lower back starts. These moments will be compared to eachother to analyse movements. All measurements together will be sent to a microcontroller. In the microcontroller it will be determined whether the received data represents a well executed squat or a squat that needs correction. If the squat needs correction it will determine the kind and place of correction needed. It will then sent a signal to the vibration motors that deliver that particular feedback. This signal will be programmed in such a way that it feels like one vibration motor moving in a certain direction.

4.2 User scenarios

Personas are created to get deeper understanding of how the users would use the wearable and why they would use the wearable. These personas are used to identify barriers, opportunities and requirements of the system. The following pages will present four different personas presenting people with different goals, reasoning and situations. The personas are created by taking inspiration from people in the direct environment of the researcher. Those people gave inspiration on where they perform the squat, how often the squat and there specific needs.



Thomas

Regular gym visitor

Age	Education	Status	Location
21	University	Trains 4 times a week	At the gym

Goals

- Wants to gain a lot of muscle.
- Works hard for a good summerbody.

Background

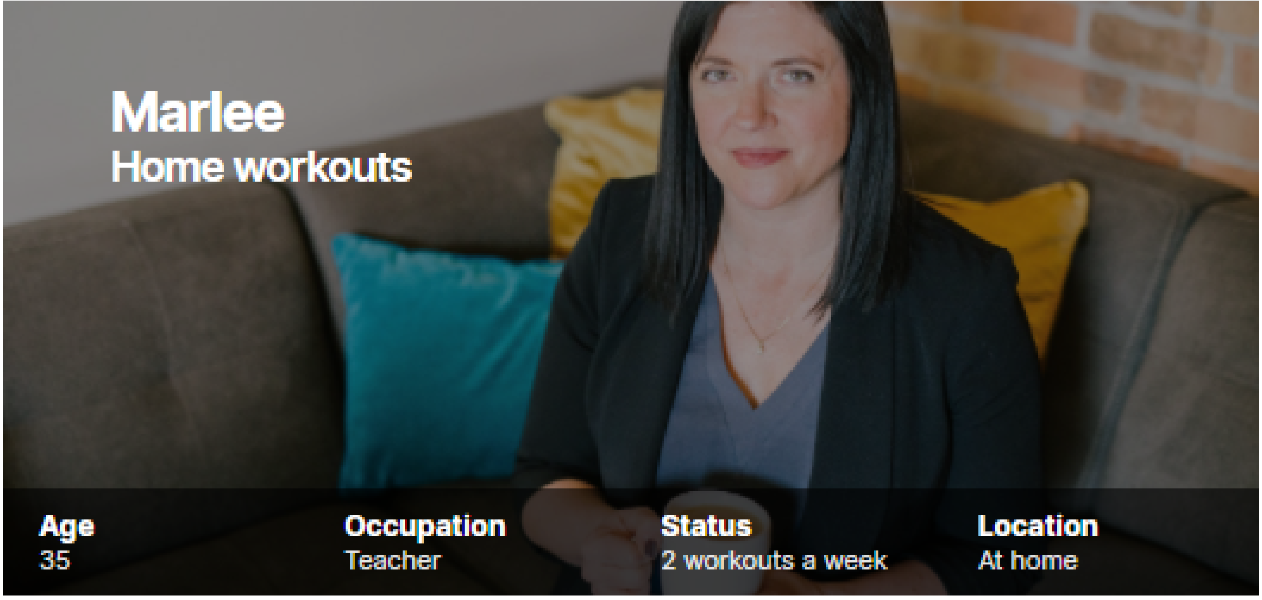
Thomas is a regular gym visitors, in the gym he mostly focuses on calisthenics which is a body based workout. One of the exercises he performs regularly is the squat, it trains his quadriceps but also burns calories. During the covid-19 pandemic Thomas replaced parts of his training scheme with at home workouts in which he follows video's made by his home gym. He will continue with these home workouts because they save a lot of time in his busy schedule.

Needs

- Because Thomas uses the squat for cardio as well he needs to be able to recognize the feedback even if he is very tired.
- Thomas is a experienced squatter, a functionality that will help him squat a bit longer every time will benefit his muscle gain.
- The wearable must not limit Thomas in any way.

Useage

Thomas will use the wearable whenever he does squats for a long time, he knows that if he gets tired his posture during the squat will change and that he has more muscle improvement if his posture stays correct during the whole squatting session. The haptic feedback will mostly work as a reminder of staying focused on his posture.



Goals

- Wants to lose weight
- Wants to keep fit after she lost the weight she wants to lose.

Background

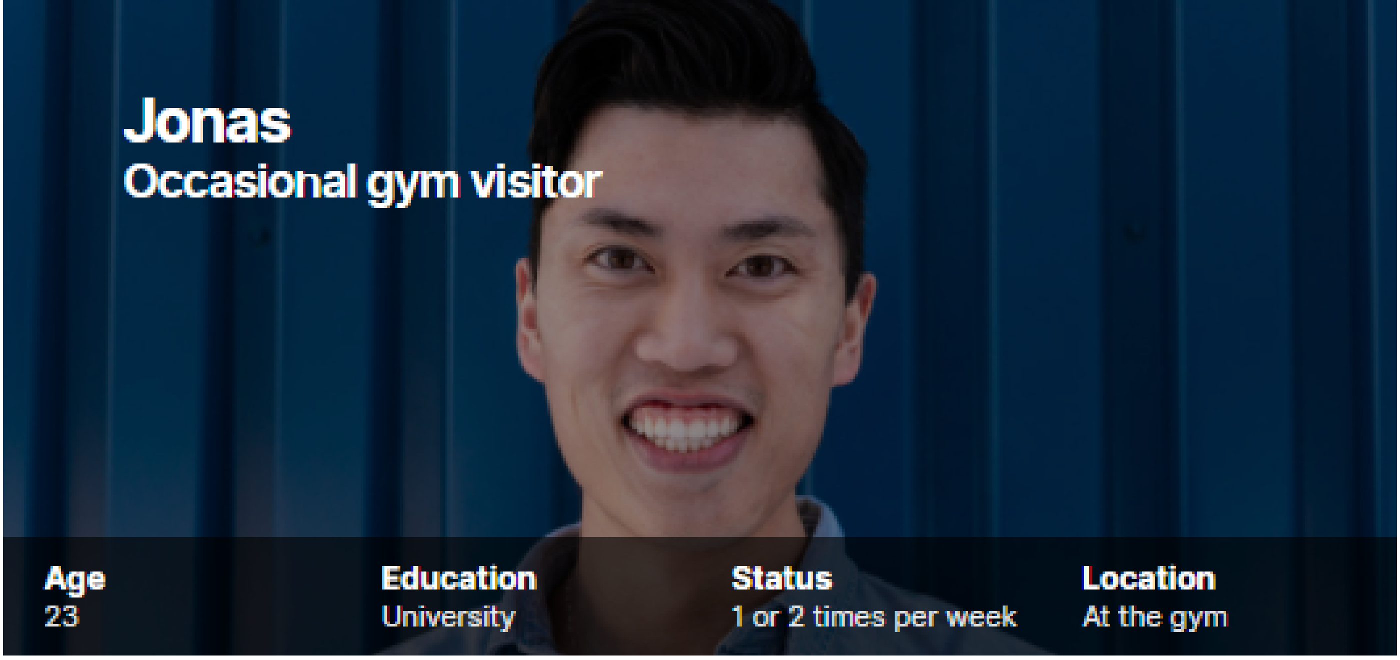
Marlee decided that she wants to lose 5 kilogram, to lose this weight she will follow a youtube channel that uploads a workout two times a week. She is very loyal in following the video's. The youtube video's almost always include the squat. Marlee has the feeling that her posture during the squat is not optimal but she has no acces to a trainer that can help her with her posture.

Needs

- Because the video's are not just squats Marlee needs to activate the wearable only when the squat is done.
- Because Marlee is no expert she needs feedback that indicates what she needs to change.
- Marlee has little experience with electronics and wearables so the interaction with the wearable needs to be intuitive.

Usage

Marlee will use the wearable in all of her workouts, she activates the wearable with the press of a button when she starts squatting. During the exercise she will carefully focus on the feedback that she receives. She is not hurried and has a lot of time to interpret the feedback. Marlee would benefit of a one time step by step explanation of the squat.



Jonas
Occasional gym visitor

Age	Education	Status	Location
23	University	1 or 2 times per week	At the gym

Goals

- Wants to stay healthy
- Keep current body shape

Background

Jonas mostly works out when he feels like working out, if he doesn't want to go to the gym he won't go to the gym. He goes to the cheapest gym possible where no proffesional is available to support him. He wants to start with weighted squats but has a history with back injuries so is very reluctant in doing the weighted squat.

Needs

- Security of good posture to prevent back injury.
- No obligation to use the wearable.

Usage

When Jonas visits the gym he will use the wearable if he brought it, he will probably forgot sometimes. Only if he brought the wearable he will do weighted squatting. He mostly uses the wearable to assure a good posture, which prevents a back injury.

Myrthe
Home gym

Age	Occupation	Status	Status
28	Entrepreneur	3 Workouts a week	In her home gym

Goals

- Works out for a good spirit and figure.
- Set a personal best for a weighted squat.

Story

Myrthe mostly works out in her shed, in the shed she build a home gym in which she has some weights, a barbel, pull-up bar and bench press equipment. She often works out 45 minutes after she gets home from work. She is really invested in gaining muscle and improving herself.

Needs

- Help improve her workout session in effectiveness.
- Injury prevention during a weighted back squat.

Useage

Myrthe wants to work out as effective as possible in her 45 minutes session. She will use the wearable in a weighted an non-weighted squat. In the weighted squat this is for injury prevention, in the non-weighted squat her focus is on keeping good posture when she is tired.

4.2.1 Conclusion

The personas show a number of aspects that need to be taken into consideration. They enable conclusions to be drawn regarding goals, target group and functionality.

The personas show that the goals of using the wearable can be very different. They show that there is a difference in using the wearable as beginner or expert, the wearable is useful for both but the type of usage can be very different. This is illustrated in the personas by looking at the personas of Thomas and Marlee, Thomas uses the wearable for perfecting his squat routine while Marlee uses it to improve her posture.

Related to the goals of the users, the personas showed that the target group is wider than initially expected. Because the wearable can work for different types of goals and proficiency levels it will work for everybody who performs the squat on a regular basis and does not have a trainer.

Both these factors contribute to the realization that the initial idea needs to take into account some other aspects as well. The first one is the need to be intuitive, the wearable needs to be basic and clear so that it can be operated even with little knowledge about electronics. A second aspect to be taken into account is the need to focus more on injury prevention when performing a weighted squat. A third aspect not covered before is that the wearable needs to switch on and off rather easy, this will allow the user to switch on the wearable during a workout that includes other exercises.

4.3 Stakeholders

A stakeholder analysis has been conducted to identify relevant stakeholders. In the scope of the graduation project the only relevant stakeholders are the researcher and the end user. To still have useful results the analysis is carried out as if the wearable would be under development at a company. A stakeholder analysis matrix is shown in figure 7. The analysis below is based on this matrix.

Researcher The researcher has the most important role in the analysis, most of the testing and development is done by the researcher which makes him the most important stakeholder.

End user The end user will be the one who purchases and uses the product once it is available on the market, the product is made for the end user and therefore has a high stake in the product and is highly affected by the product.

Company The company that produces and develops the product is an important stakeholder but its interests can be broken down into three separate components.

Management The management of the company has much influence in the design process but management is not directly affected by the product itself. Management should be satisfied but no direct cooperation is necessary.

Assembly The assembly of the product is also relevant, assembly of the product and quality standards should be monitored. There should be communication between the researcher and assembly team but no direct involvement is necessary.

Programmer The programmers that are part of the development team will have influence on the product by programming it correctly. This team will have direct influence on what is and what is not possible. This requires close communications.

Trainer Trainers are stakeholders because the wearable is relevant for their job, although the wearable does not set out to replace a trainer it can support the trainer. So a good plan of action would be informing trainers about the workings of the wearable.

Gym Gym's are stakeholders because the wearable does not replace a trainer it does stimulate home workout's. This will influence the gym as a company.

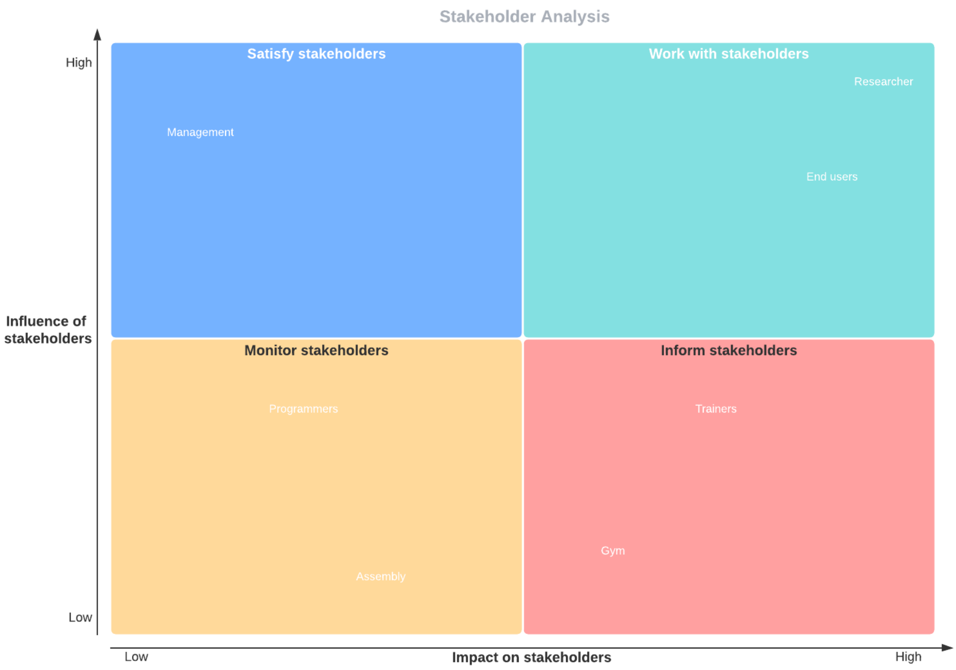


Figure 7: Stakeholder analysis matrix

5 Specification

Specification is needed to be able to create a working prototype that is ready for testing. In this chapter the specification is done by addressing the requirements, type of interaction and the individual parts of the wearable. This chapter mainly contributes to answering the research question: How to design a wearable tat improves posture during the squat by providing haptic feedback. The sub research questions answered in this chapter are: 1. how can data be retrieved from the sensor and properly filtered? 2. what is useful and understandable feedback? 3. where do we place the sensors and actuators on the body?

5.1 Requirements

A list of requirements can be drawn up after exploring the initial idea, user scenarios and input by stakeholders. This will provide a clear goal and a good reference for the evaluation of the wearable. The requirements are set up with the MoSCoW method [27], this helps prioritizing requirements into 'must have', 'should have', 'could have' and 'won't have'. These are listed below.

Must have

- The wearable must be able to recognize squat patterns and properly analyse those patterns.
- The wearable must be able to provide haptic feedback at the correct place.
- The sensors and actuators must be integrated into a wearable.

Should have

- The wearable should have an easy understandable feedback pattern that indicates direction.
- The wearable should not be constraining the user during the exercise.
- The wearable should be intuitive to use.
- The wearable must have a button that allows for easy on and off mode.

Could have

- The wearable could be a closed system for the processed data.
- The wearable could be powered from a battery pack in the wearable.

Won't have

- The wearable will not be able to provide feedback using machine learning.

- The wearable will not have more functionalities.

The 'must haves' requirements specify the minimum requirements of the wearable. Without any of the three must have requirements the wearable would be useless. If the wearable is not able to recognize a pattern or provide feedback it will just be a piece of clothing without function. If the wearable is not placed on the body it will not be able to measure the correct parameters. Integration of the sensors and actuators into the wearable is a must, it would make the positions of the sensors constant which allows for better measurements.

The 'should haves' requirements are based on a brainstorm session to improve the wearable. Easily recognized feedback will make the wearable more intuitive in overall use. An intuitive wearable will be easier for sporters to use and make them feel comfortable. The second requirement is that it should not constrain a user during the exercise, this would annoy the users which could make it less likely for the user to use the wearable.

The 'could haves' requirements are requirements that can be integrated if time allows. This is to assure that no data can easily be extracted from the wearable to make sure the users data is private. Another requirement is to power the wearable from a battery pack. This requirement is in could have because for testing the wearable needs to be connected to a laptop to gather data for further analysis. This means that in the testing phase no battery pack is needed.

The 'won't haves' are requirements that were shortly considered to be included but considered as not achievable within the scope of this bachelor thesis. Machine learning would allow for more precise and better feedback but after talking to a machine learning expert it was deemed too difficult to create a neural network within the scope of this bachelor thesis. Inclusion of more functionalities, like different exercises were considered to take up too much time.

5.2 Initial design

The initial idea regarding the placement of the sensors and the vibration motors is shown in figure 8. In short, this is an IMU on the bone just below the knee and an IMU on the lower back. The vibration motors are placed on the side of the hip and on the side of the knee. This placement is determined as start of the iteration process in chapter 2 This placement is further detailed in section 5.6. The used components are based on the conclusion from chapter 2.

5.3 Interaction

Two interaction patterns are important for the wearable, the interaction between IMU's, microcontroller and vibration motors and the interaction between wearable and user. The wearable should have reliable and real-time interaction between the different components. The components should be able to sense

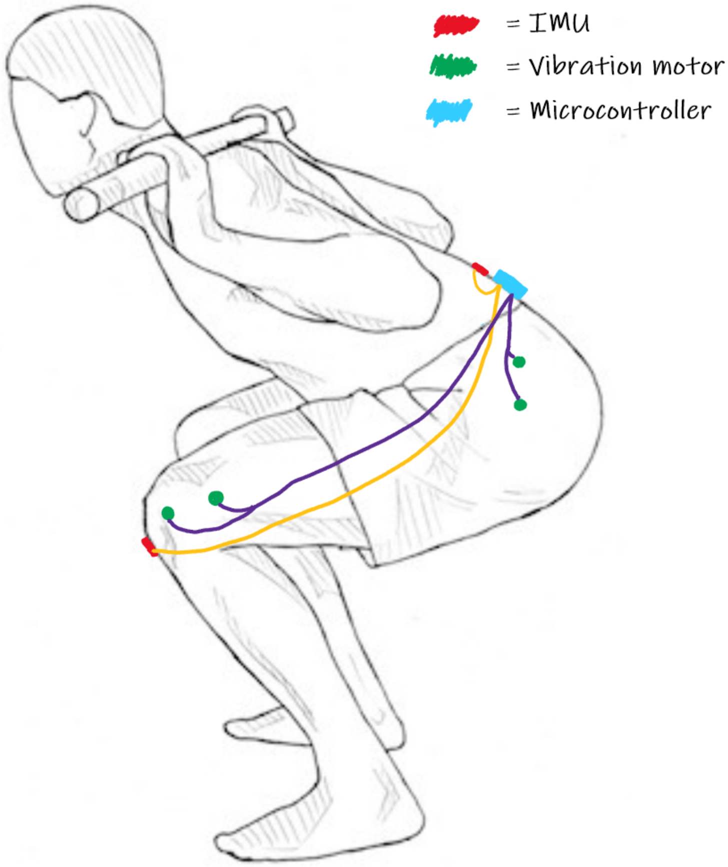


Figure 8: Drawing of the initial setup [28].

that a squat is performed, measure whether the squat is performed correctly and in case the squat is not performed correctly sense where posture needs to be improved. After these is measurements the wearable should be able to interact with the user at the place where posture needs to be improved by giving intuitive, directional and reliable vibrations. The working of the sensor will be further elaborated in section 5.4 and the feedback in section 5.5. A scenario will be given to further clarify the interaction.

After the user gets the idea to follow a workout online, he starts YouTube on his laptop and clicks a video by his favorite workout YouTuber. Before starting he puts on his squatting wearable to assure a correct posture during the squats to perform. After two minutes of working out his video-trainer will start performing a squat. He presses a button on his wearable and a light starts shining, indicating that the wearable is switched on. The first few minutes go very well and without getting any feedback. After 5 minutes he gets tired, and really needs to work to get up again. This causes his body to bend the knees more forward to reduce the work that needs to be done by the muscles. Now he gets an vibration pattern on the knee. This vibration indicates that he has to pay attention on how far he bends his knee. After some time the video-trainer stops doing squats and moves to push-ups; he switches off his wearable and performs the push-ups.

5.4 Sensing

Sensing will be done using the IMU; IMU stands for Inertia Measurement Unit. An IMU can measure rotation and acceleration. The use of multiple IMU's enables measurement of positions of key body joints thus measuring the posture of the user during the squat.

5.4.1 MPU 6050

The used IMU is the MPU 6050, produced by Ivensense. It has two distinct parts, the accelerometer and the gyroscope, this means that it will measure six distinct values, three values for both parts. In essence the MPU merges two sensors into one device.

The accelerometer will measure the acceleration in g [m/s2]; 1g is equal to 9.81 [m/s2] which is the gravitational acceleration. The accelerometer measures the acceleration for the x, y and z axis, from which a magnitude and directional force can be derived. If the MPU is put on a flat surface the accelerometer values will read:

- x = 0g
- y = 0g
- z = 1g

This indicates that the accelerometer also measures gravity. Figure 9 clearly visualizes how an accelerometer works; note that in figure 9 gravity has been neglected.

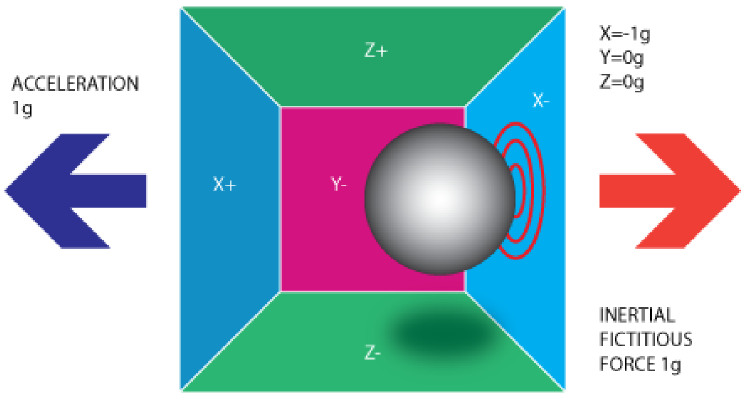


Figure 9: Visualization of the workings of an accelerometer [29].

Figure 9 shows a movement to the left side, this puts a pressure on the right side. The magnitude of this pressure is sensed by the accelerometer, telling the accelerometer that there is an acceleration to the left side of the magnitude measured.

The full range of the accelerometer is ±16g, ±16g is not necessary for the wearable. A user will never be able to produce an acceleration of ±16g during the squat. The MPU gives an option to set this range;

it can also be set at ±8g, ±4g or ±2g. A lower range increases the sensitivity of the accelerometer [30].

The gyroscope will measure the rotation in deg/s. The gyroscope measures the rotation for the x, y and z axis. If the MPU is put on a flat surface the values for the gyroscope will read:

- x = 0 deg/s
- y = 0 deg/s
- z = 0 deg/s

It is important to note that the gyroscope measures degrees per second and not the actual rotation. This means that a gyroscope reading of 50 deg/s does not mean the gyroscope turned 50 degrees. For the actual rotation the frequency is needed, from which the measurement time can be calculated. Using the measurement time the actual rotation can be calculated using: measurement value x measurement time, which is the same as integrating the measurement value.

The full range of the gyroscope is ±2000 deg/s. The MPU gives the option to set this range, it can also be set at ±1000 deg/s, ±500 deg/s or ±250 deg/s. A lower range increases the sensitivity of the gyroscope [30].

The pin layout of the MPU 6050 is given in figure 10. A more detailed description regarding the used pins is given above figure 10 [31].

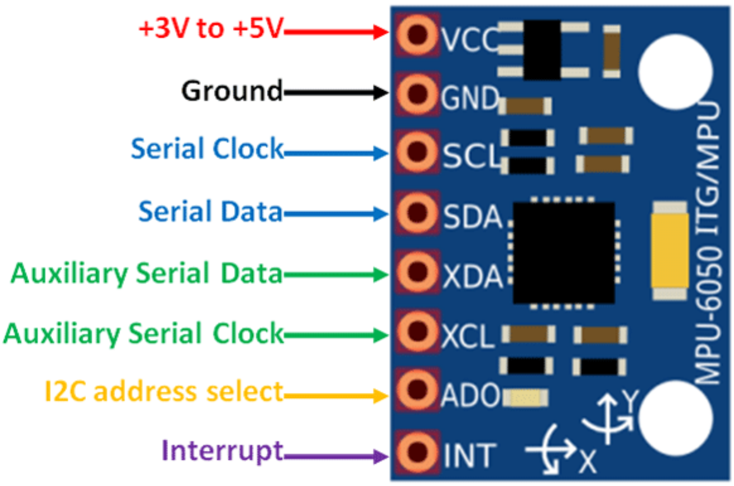


Figure 10: Pin layout of the MPU 6050.

- VCC = powering the MPU
- GND = connection to the ground
- SCL = data port, used for communication with the Arduino

- SDA = data port, used for communication with the Arduino
- ADO = used in the i2c bus for communication with 2 MPU's

The full connection scheme of the setup can be found in figure 11 and figure 12; the scheme is created using Fritzing [32].

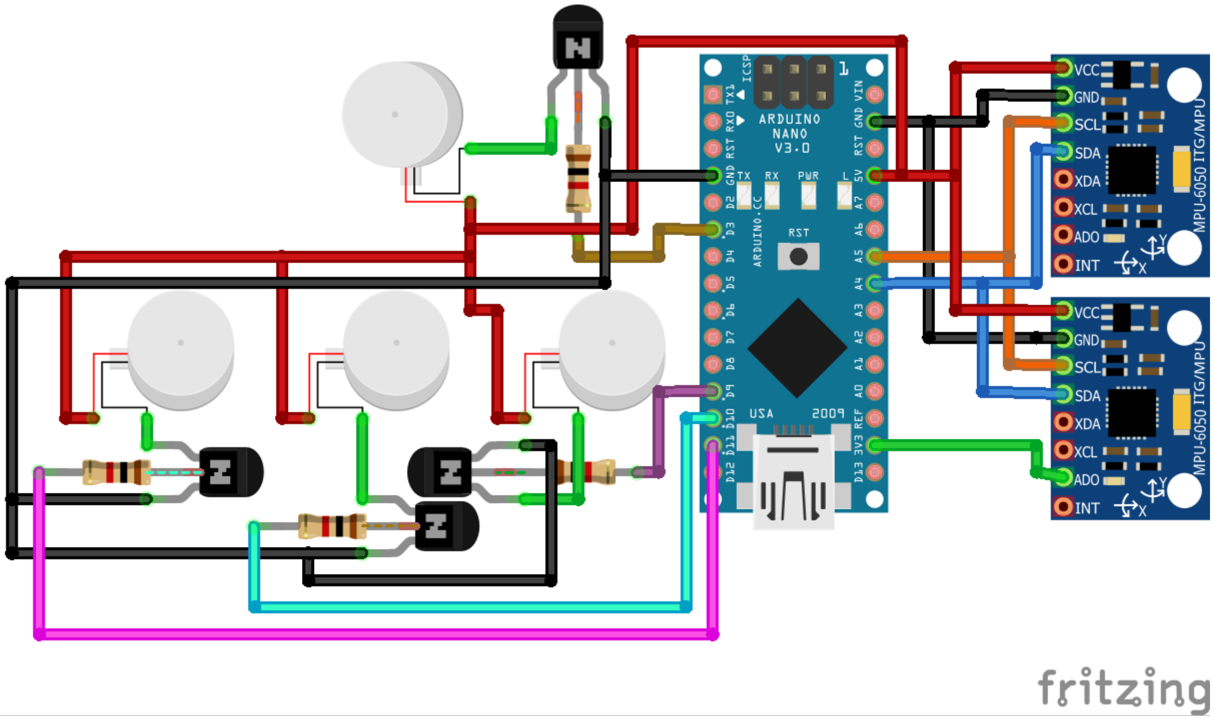


Figure 11: Full connection drawing.

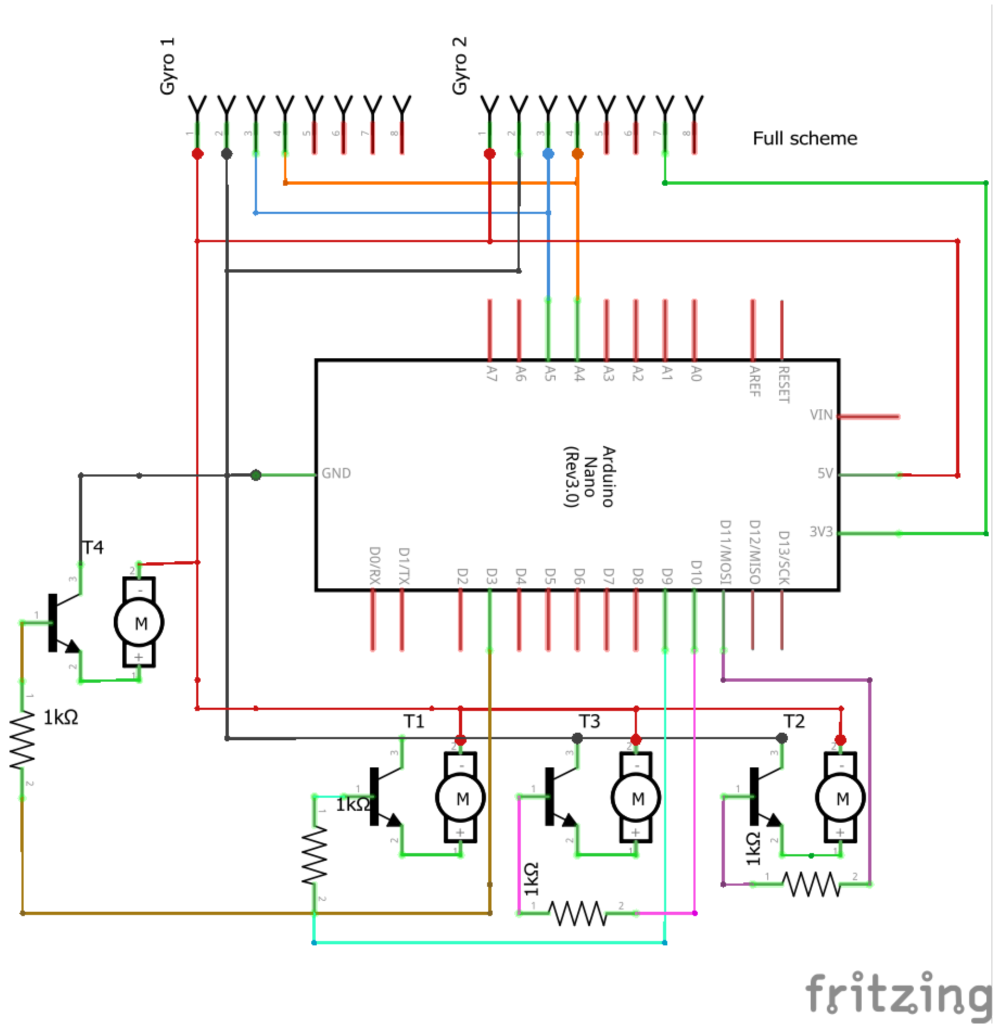


Figure 12: Full connection scheme

The MPU 6050 has an I2C protocol, which allows for connection with two MPU's without needing more analog pins from the Arduino. One digital output of the Arduino is used to set the ADO pin of the MPU to high, which will give the MPU the address (0x69), the default address is (0x68). This connection can be found in figure 11 and figure 12.

5.4.2 Placement and detection

As discussed in section 5.2 the MPU's will be placed on the knee and the lower back. The reasons for this choice are given in chapter 2. The actual measurements at these locations are explained in this section.

The knee MPU will measure absolute position in relation to the position before. When performing the squat the knees will move to a certain position. By analyzing patterns it can be determined when the knee is in peak position. Comparison of this angle with the rest position enables determination of the movement of the knee. In case this movement is above or below the threshold values the wearable needs to give feedback to the user.

The lower back will also use the absolute position of the IMU on the lower back, in particular the back bone. It will measure whether the backbone does not change from hollow to bulging.

The knee and lower back will also work together, the lower back needs to move before the knee is moved. So both IMUs measure when an acceleration takes place, these times will be compared with each other and feedback will be given when the knee moves before the lower back.

5.5 Feedback

Feedback will be provided with haptic feedback. This feedback is produced using multiple vibration motors. The feedback will be given at relevant placing, so the place of the feedback is related to the posture improvement.

5.5.1 Vibration motor

The used vibration motor is a 10 mm vibration motor - 3 mm type, model 310-101. Its rated operation voltage is 3V and the rated operation current is 63mA [33].

For safe usage a vibration motor is connected to the Arduino with a transistor and a resistor. The connection scheme is presented in figure 11 and figure 12.

PWM pins are used for controlling the vibration frequency of the vibration motor;these pins provide an adjustable output voltage. An informal test on the researcher has been conducted to check for a frequency that is noticeable under high cognitive load but does not feel intrusive. Results are given in section 5.5.2.

5.5.2 Experiment 1: Frequency

Experiment 1 sets out to find a good frequency that is noticeable under high cognitive load but does not feel intrusive for the user. This is done by placing a vibration motor at three positions around the knee and lower back. The code iterates through different frequencies and the vibration will be rated for notability and intrusiveness. Max voltage during the tests was 5V which is related to 255 in the code, Min voltage was 0V which is related to 0 in the code. A quick iteration showed that only the range 40-140 needed to be included because below 40 no vibration was noticed and above 140 no change was noticed. The results are shown in tables 1 and 2.

These include different placements on the body, every setting has been given a mark at the scale of 1-10, where one is not noticeable or very intrusive and 10 is clearly noticeable or not intrusive.

The results show that the optimal setting is 70 or 80, to be sure that the vibration is noticeable under high cognitive load the setting for the vibration motor will be 80; this corresponds to a voltage of: (5/255)*80 = 1.57V. Figure 13 shows that this corresponds to a frequency of 120 Hz. This corresponds with the range of 80-500 Hz given in section 2.1.2.

	Inside knee	Outside knee	Outside quadriceps
40	1	1	1
50	5	5	5
60	7	7	7
70	8	8	7.5
80	9	9	8.5
90	8	8	8.5
100	6.5	6.5	6.5
110	5	5	5
120	3	3	3
130	3	3	3
140	3	3	3

Table 1: Experiment 1.1: Positioning on the knee on a scale of 10.

	Hip	Middle of lower back	Side of lower back	side
40	1	1	1	1
50	7	7	7	4
60	7.5	7.5	7.5	5
70	8.5	8.5	8.5	6
80	8	8	7.5	6
90	7	7	7	6
100	6	6	6	3
110	5	5	5	3
120	4	4	4	3
130	4	4	4	3
140	4	4	4	3

Table 2: Experiment 1.1: Research on positioning on the lower back on a scale of 10.

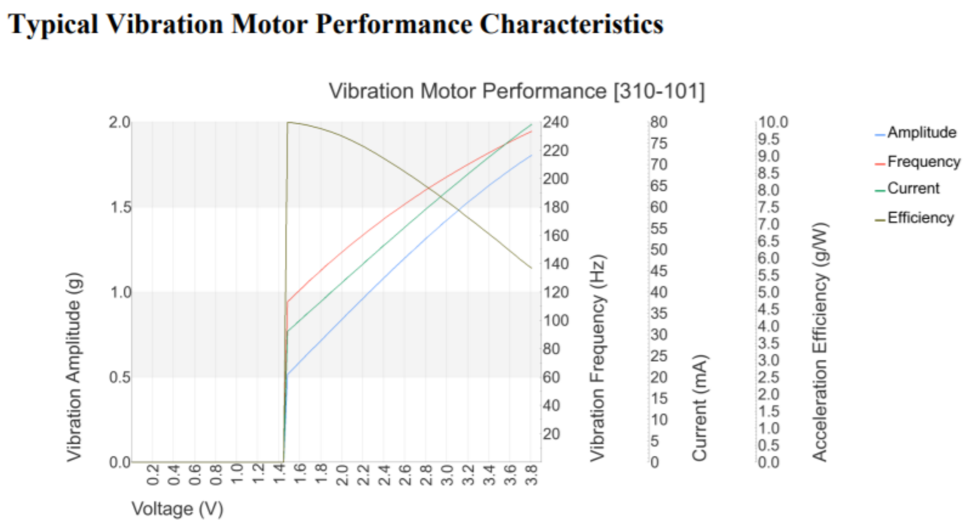


Figure 13: Chart on voltage frequency relation of the vibration motor [33]

5.5.3 Experiment 2: Placement

Tables 1 and 2 show that multiple positions have been tested. The positions of the vibration motors are shown in figure 14. Only a small range of positions has been selected, these are the positions that are related to where posture needs to be improved. These positions will now themselves be tested to determine a good position for the feedback. This was done by placing a vibration motor on either the inside knee, outside knee, outside quadriceps, hip, middle of the lower back, side of the lower back or the side. The used frequency was 120 Hz. The experiment was rated for user comfort and connection. Connection rates how easy it is to implement a vibration motor at that position in the wearable. The results are given in table 3. The positions are rated on a 1 to 10 scale, where 1 is no comfort or a difficult connection and 10 is very comfortable and very easy connection.

	Comfort	Connection
Inside knee	6.5	8
Outside knee	7.5	8
Outside quadriceps	7	8
Hip	7	5
Middle of lower back	8	9
Side of lower back	7.5	8.5
Side	5.5	8

Table 3: Experiment 2.1: Research on positioning vibration motor on a 1 to 10 scale.

Figure 14: Placement of the vibration motors for experiment 2.

It can be concluded from table 3 that the best positions for the vibration motors are the outside of the knee and the middle of the lower back.

5.5.4 Vibration patterns

In section 2.1.2 it has been shown that optimal positioning for a feedback pattern is 6cm apart. Figure 15 shows how vibrotactile patterns are perceived if the vibration motors are 6 cm apart for different activation points [17].

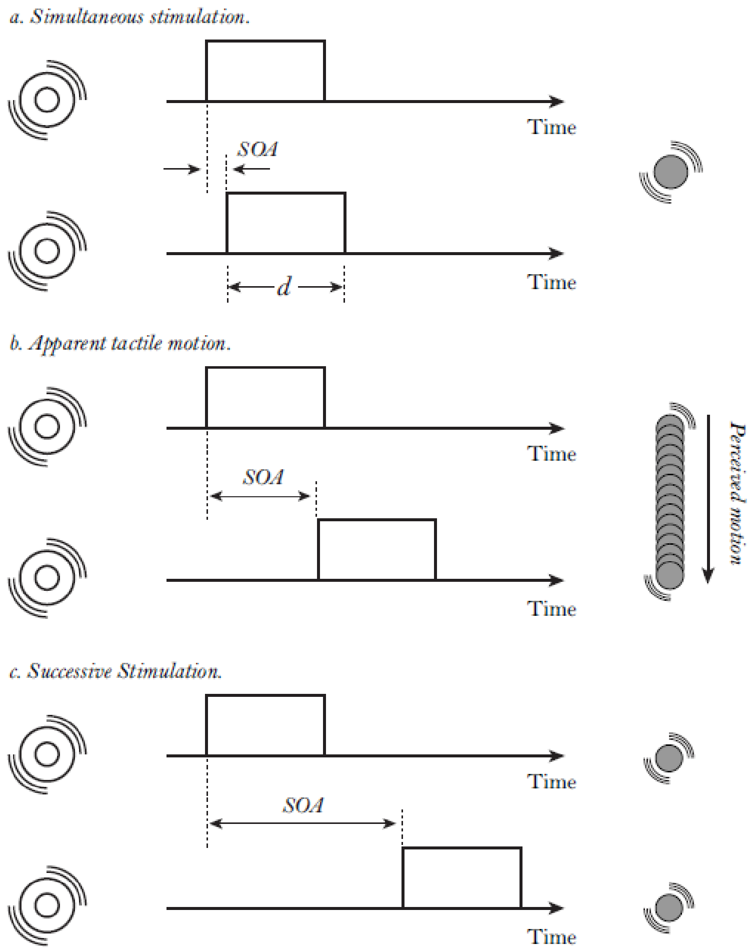


Figure 15: Vibrotactile perception [17]

Israr et al. [17] also studied the SOA (Stimulus Onset asynchrony); the results of this study are given in figure 16. This gives a starting point for the experiment into finding good pattern settings; this experiment is discussed in section 5.5.5.

5.5.5 Experiment 3

Experiment 3 sets out to find proper settings for directional feedback. This means that the direction in which the pattern moves should be clear and the vibration should be clearly noticeable for the user. The last point of assessment is whether the pattern is smooth. The outcome of the experiment is presented in three different tables, each representing one iteration of the experiment.

In this experiment the vibration motors are attached to the outside of the knee. The vibration motors are kept 6 cm apart by cutting a piece of cardboard of 5.5 cm and placing the cardboard between the

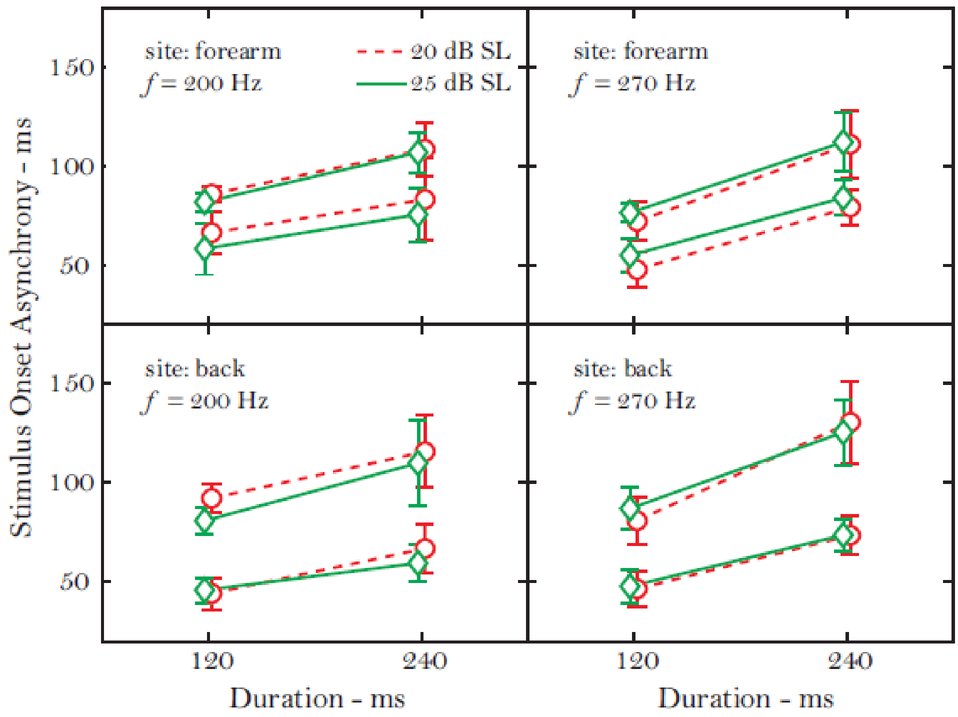


Figure 16: SOA thresholds and control space [17]

vibration motors. Cardboard and vibration motor are surrounded by sporting tape to assure a rigid construction. The construction is shown in figure 17; the attachment is shown in figure 18. The code was set up to give one feedback pattern every two seconds; two different patterns are going into opposite directions. The information about experiment 3.1 is given in table 4.

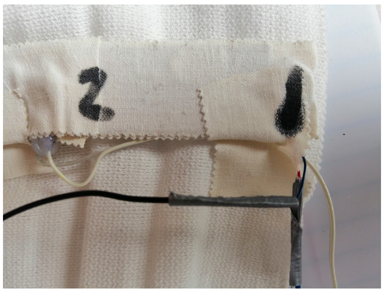


Figure 17: Vibration motors merged together to assure 6 cm distance.

	Setting 1 in [ms]	Setting 2 in [ms]	Setting 3 in [ms]	Directional	Noticeable	Smoothness
1	500	150	500	5	7.5	5
2	400	100	400	5	7.5	5
3	100	20	100	6	6	9

Table 4: Experiment 3.1: Testing vibration patterns on direction clearness, Notability and smoothness. (frequency 120 Hz)

Three settings are displayed in table 4. Setting 1 is the SOA time. Figure 15 shows that this is the time that the first motor vibrates before the other motor starts vibrating. The second setting is

Figure 18: Attachment of the vibration motors to the body during a squat.

the overlapping time when, both motors vibrate. The third setting is the time that the second motor vibrates alone.

Table 4 shows a big step in settings, this is based on findings by Israr et al. [17]. The experiment did not show the expected result so some research was done and the paper by Israr et al. [17] was reviewed. Figure 16 in this paper showed a good SOA setting of max 100 ms which is much lower than the used 500. So settings with a SOA time of 100 ms were used resulting in a strongly improved motion; but this was poorly noticeable. Another review of figure 16 showed that this was run at a frequency of 200 Hz while the experiment ran at a frequency of 120 Hz. In table 5 the frequency has been set to 200 Hz.

	Setting 1 in [ms]	Setting 2 in [ms]	Setting 3 in [ms]	Directional	Noticeable	Smoothness
1	100	20	100	7	7	9
2	150	40	150	7	7	6
3	150	20	150	7	7	7
4	120	20	120	8	7	9

Table 5: Experiment 3.2: Testing vibration patterns on direction clearness, Notability and smoothness. (frequency 200 Hz)

With a higher frequency the overall results were improved, the feedback was better than in experiment 3.1. Al though the results were better, there was more room for improvement, especially the direction was still hard to detect during the execution of the squat. It was decided to add another vibration motor to the sequence to extend the total duration of the feedback and to assure that the direction of the feedback was clear. Figure 19 shows the new connection between the thee motors, the attachment to the body is the same as in figure 18. The results of experiment 3.3 are given in tables 6 and 7.

In table 6 only two settings are recorded. More small changes have been tried but none of these gave noticeable differences with the two recorded settings. The settings in line 2 will be used for the

Figure 19: Three vibration motors joined together to assure 6 cm distance.

	Setting 1 in [ms]	Setting 2 in [ms]	Setting 3 in [ms]	Setting 4 in [ms]	Setting 5 in [ms]
1	120	20	120	20	120
2	100	5	95	5	100

Table 6: Experiment 3.3: settings of vibration patterns on direction clearness, Notability and smoothness. (frequency 200 Hz)

	Directional	Noticeable	Smoothness
1	9	8	8
2	9	7.5	9

Table 7: Experiment 3.3: Results of vibration patterns on direction clearness, notability and smoothness. (frequency 200 Hz)

wearable.

5.6 Attachment

Proper functioning of the wearable to function requires firm attachement to the body. The IMU needs to be placed against the skin for optimal measurement. Two places are important, lower back and knee.

A knee band will be used for the knee, these already exist to provide support during walking or sports activities [34]. The IMU and the vibration motors will be integrated into the band. The fabrication of the band allows for adjusting the size according to the person wearing the band.

The microcontroller can be placed in a comfortable band around the waist, placing this at the back of the user. This means that the IMU and vibration motors can be integrated into band. This will be adjustable in size so it can be worn tight so the IMU will remain in contact with the skin.

5.7 Arduino Nano

The Arduino Nano is a small microcontroller that allows for easy programming and offers a lot of options. Because the Nano is small and light it will not constrain the user during the squat. The pin layout is shown in figure 20. A list iwth the used pins is given below figure 20.

- Vin = Powering the Arduino with 5V from an external power supply.
- GND = Connect the ground of the power supply.

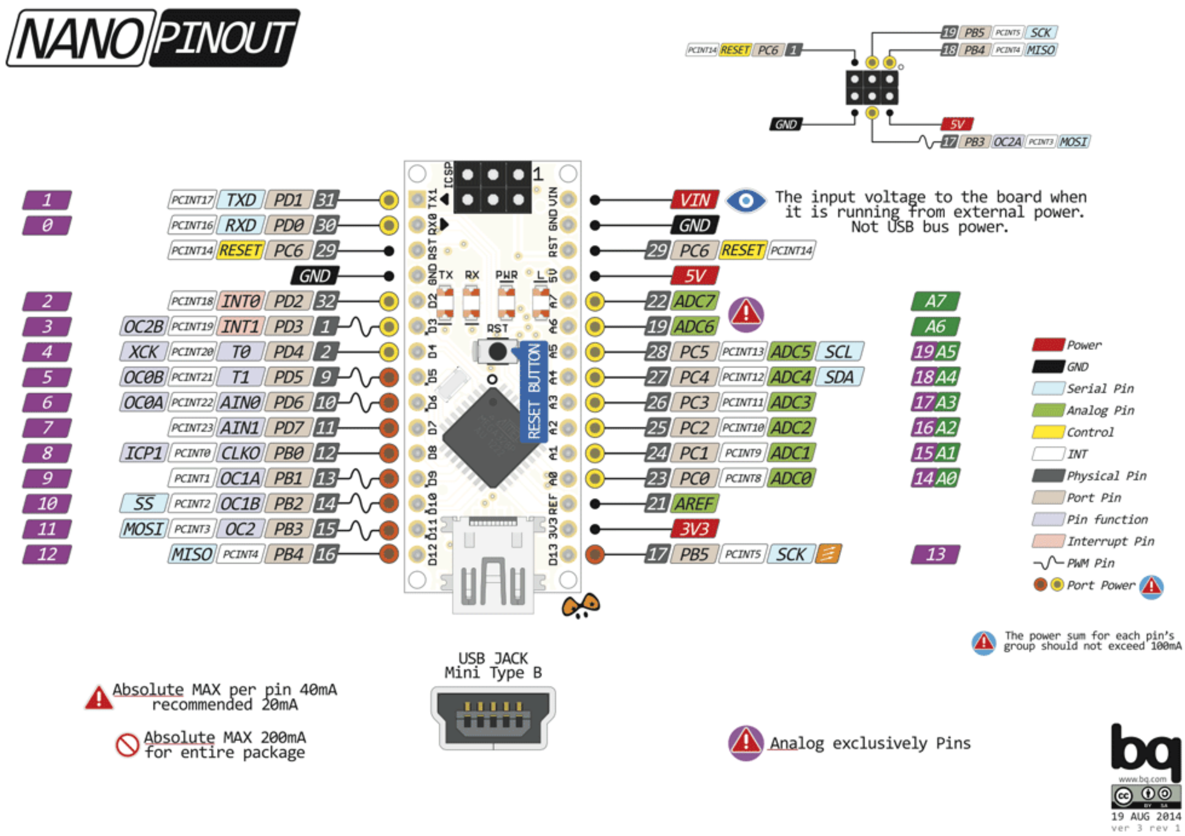


Figure 20: Arduino Nano pin layout[35].

- A4 = SCL pin to be connected to the SCL pin of the MPU.
- A5 = SDA pin to be connected to the SDA pin of the MPU
- 3.3V = Used to power the MPU's.
- D3/D5/D6/D9/D10/D11 = PWM pins that will be used for controlling the vibration motors.

5.8 Conclusion

In this chapter all components that are needed to make the wearable are specified, detailed descriptions are given to create understanding on how the components are used and in which way the components need to be used. Especially the IMU and vibration motor are thoroughly discussed because those components form the center of the wearable.

The used IMU will provide an absolute position and acceleration from which patterns can be analyzed so it can be determined when and where the user needs to receive feedback. Connection schemes are provided to assure the data can be received properly by the Arduino Nano. This answers how the data can be retrieved from the sensors.

A good starting frequency and position of the vibration motor have been determined by experiments on the researcher. This showed that the optimal frequency is 120 Hz which corresponds with a voltage level of 1.57V. The best positions for the vibration motors are the outside of the knee and the middle of the lower back. Later research into vibration patterns showed that the frequency of 120 Hz is too low for haptic patterns, a frequency of 200 Hz works well in these circumstances, a frequency of 200 Hz will therefore be used in the wearable. The vibration pattern will also use three vibration motors to provide the feedback. This answers how useful and understandable feedback can be given.

The IMU and vibration motor also need mutual communication, for which the Arduino Nano is used, it is light-weight with enough computing power and pins to control the wearable. Custom code will be created and uploaded to the Arduino Nano to control the IMU and determine when and where feedback needs to be provided.

6 Realization

A working setup is needed for the realization of the wearable. Such a setup requires the wearable:

- To compare set parameters with the measured parameters
- To give meaningful feedback at the correct place and time
- To be easily switched on and off
- To not obstruct the user while wearing the wearable

These requirements need to be met to have a functionable wearable that can be used for the user tests. The full requirements are given in section 5.1.

6.1 Setup

The specifications of the wearable are discussed in chapter 5. These will briefly be recapped in this section to obtain a clear overview of the final setup and the reasoning behind the setup. After the overview a visualization will be given in figure 21.

6.1.1 Measurement

One IMU will be placed on the front of the knee and another will be placed on the lower back. This is displayed in figure 8. The IMU is placed on the knee because it measures how far the knee goes outward; the front of the knee is chosen because it allows for easy measurement of the angle of the knee opposite the floor. Another reason is that the front of the knee has a bone that is close to the skin. The IMU works better placed on a bone than placed on a muscle because a bone only moves with the movement itself while a muscle can give some damping or oscillations. The other IMU is placed on the lower back to measure the angle of the backbone, because the backbone is joint that needs to be measured and the advantage that is a bone so no damping or oscillations results in placing it exactly on the backbone.

6.1.2 Feedback

Feedback is given by one set of three vibration motors and one standalone vibration motor. The set of three is placed at the side on the knee and the standalone on the lower back. Both these positions are the result of experiments described in chapter 5. The three vibration motors and the corresponding settings are also resulting from experiments described in chapter 5.

6.1.3 Button

The on/off button is included to allow for easy on/off switching while exercising. This means that it needs to be accessible for the user without risk of accidentally pushing the button. The button will be placed in the sequence of vibration motors on the knee. The knee has better accessibility than the back and still allows for integration into the design.

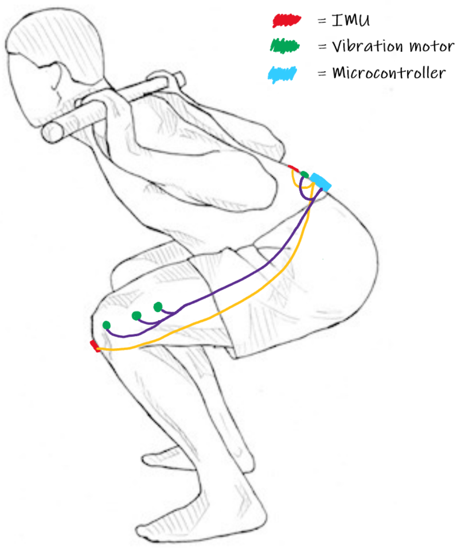


Figure 21: Drawing of the final setup [28].

6.2 Code

The code is very important for the realization of the setup. The code forms the heart of the setup. It processes the data from the IMU and controls the vibration motors. The code has different aspects, each with their own functionality. The full code is given in appendix B.1.

6.2.1 Retrieving data

The data from the IMU are retrieved with the MPU 6050 library. This library initializes the IMU and has a built in function that retrieves the data from the IMU every iteration. This is combined with the I2C library by Jeff Rowberg [36]. This library allows for communication through the I2C protocol and reads out two IMUs with the same number of pins. The library also allows for control over the range of the IMU; tests shows that the max in g that is achieved during a squat is below 8g and 1000 deg/s. Because the full range (16g and 2000 deg/s) is not required a lower range can be used which increases sensitivity.

6.2.2 Filter

The data coming from the IMUs is going through a moving average filter; this filter takes the last 25 data points and calculates the average of these data points. The filter returns the average as the measurement. If new data comes in the last data point is removed from the list and the new measurement is added. This results in a new average that is returned.

6.2.3 Conversion

The data coming in is a number between -32678 and 32678; these maximum and minimum numbers represent the maximum and minimum of the represented range. To make the data understandable it needs to be converted into deg/s or g. This is done by dividing the acquired data by the sensitivity. The sensitivities are found in the datasheet of the MPU 6050 [24].

6.2.4 Calculate angle

After conversion of the data into actual meaningful data these can be used to calculate the angle made by the IMU. This is done with the accelerometer and the gyroscope data. Finally both angles are combined with a complementary filter which returns the position of the IMU with respect to the starting point.

Calculating the angle from the accelerometer data requires some mathematics. The angle in radians is calculated with the following formula:

$$\alpha[rad] = arctan(Ay/(\sqrt{Ax^2 + Az^2}) \tag{1}$$

The following formula is used to calculate degrees from the angle in radians.

$$\alpha[deg] = (180 * \alpha[rad])/\pi \tag{2}$$

Turning the gyroscope data into an angle in degrees requires integrating the data. This is done using the following formula:

$$\alpha[deg] = prev - \alpha + gyro - data * \Delta t \tag{3}$$

In which prev angle is the previous angle that is updated by the code every iteration. Delta t is calculated by the code every iteration.

The complementary filter combines the angles from the gyroscope an the accelerometer. This is done using the following formula:

$$\alpha[deg] = (0.95 * (gyr - \alpha)) + (0.05 * acc - \alpha) \tag{4}$$

6.2.5 Timer interrupt

The inclusion of a timer interrupt assures that there is a constant output of data. A timer interrupt uses two PWM pins of the Arduino to time executions of code in the interrupt. The included timer has a frequency of 100 Hz. This means that the code is stopped 100 times per second to execute the code in the timer interrupt. The timer interrupt code prints the data and initiates a cycle variable that counts until 400 by adding 1 after every execution of the interrupt. After 400 cycles, which amounts to

4 seconds, the variable resets to zero. This counter is used for the peak detection as well; this will be further explained in section 6.2.6.

6.2.6 Peak detection

To properly rate the execution of the squat the peaks needs to be detected. The method used for testing is not sufficient for the open market; further development of the wearable following this thesis would require a more sophisticated method. During testing the participant feels a vibration on the back 4 seconds after start of the code, this is the start signal. The participant is told that this is the start signal who then has 4 seconds to perform the squat. After those 4 seconds a new vibration is sent representing the start signal for the next squat. This allows for an exact time frame in which the squat is executed, thus resulting in an easy method to detect the necessary peaks.

The variable from the timer interrupt is used to properly time the cycles. This allows correct timing of the 4 seconds, send the measured peaks at the right time, and reset the variables for the next squat. A simple explanation of the code for the peak detection is given below.

1. After 4 seconds the code starts to search for peaks.
2. The peaks are found by comparing each measured value with the maximum and minimum value already stored.
3. If the measured value is higher than the maximum it replaces the maximum, if it is lower than the minimum it replaces the minimum.
4. After 4 seconds it sends the maximum and minimum to the check-up part of the code and resets the maximum and minimum.
5. The check-up calculates the difference between the maximum and the minimum and compares the difference with the threshold value.

6.2.7 Vibration motors

If the calculated difference in the peak detection is larger than the threshold one of the four ways to provide feedback is activated. An algorithm can decide which feedback is needed, the vibration motors needed for this feedback are handled by turning a digital PWM pin into an output pin. A variable controls the frequency of the vibration motors. Because the timer interrupt stops the rest of the code the millis() function is not usable to time the vibration pattern, the delay() function is not usable either because this stops the code for a set period of time which makes the rest of the code unusable. The cycles variable of the interrupt is used to solve this. This variable is reliable for the timing, 100 cycles represent 1 second. So by using these cycles the timing can be set for the feedback patterns.

6.3 Data analysis

Data analysis needs to be carried out to assure that correct feedback is given and to answer the sub-research question: how is a correct squat identified using the data?. For these purposes 18 datasets have been collected, each dataset has 1500 measurement points which results in an average of 10 squats per dataset. The datasets are gathered by the researcher himself and three other persons, this is a necessity to design a wearable that works on a large group of people. One IMU was connected at the knee and another at the lower back. These datasets give insight into which parameters are important to measure and how to set threshold values that are fitting for a large group of people.

After analysis of all datasets it can be concluded that for the knee the gyroscope in the y (Gy) direction and accelerometer in the z (Az) direction are relevant. Gy and Az will be used to find a pattern in the forward movement of the knee. Az will also be used to determine when the knee starts to move, while a parameter from the IMU on the lower back enables drawing a conclusion on which body part moved first. For the lower back the gyroscope in the y direction (Gy) and accelerometer in the x (Ax) direction are relevant. Gy will be used to determine a pattern in the back and how far a person bends forward or backward. Ax will be used as parameter to compare with the Az from the knee.

Figures 22, 23, 24 and 25 show datasets of the described parameter. Each figure has two plots, the left plot is from a correct squat and the right plot is from an incorrect squat. These clearly show that there is a detectable difference between those plots.

Analysis of all the datasets show that it is impossible to set one workable threshold that works for a large group of people. So to be meaningful for the individual these thresholds need to be adjusted for every user. This will be done by performing baseline squats, 5 squats during which peaks will be measured and averaged to set as thresholds. These thresholds will be used to rate the squats that are performed after the baseline squats.

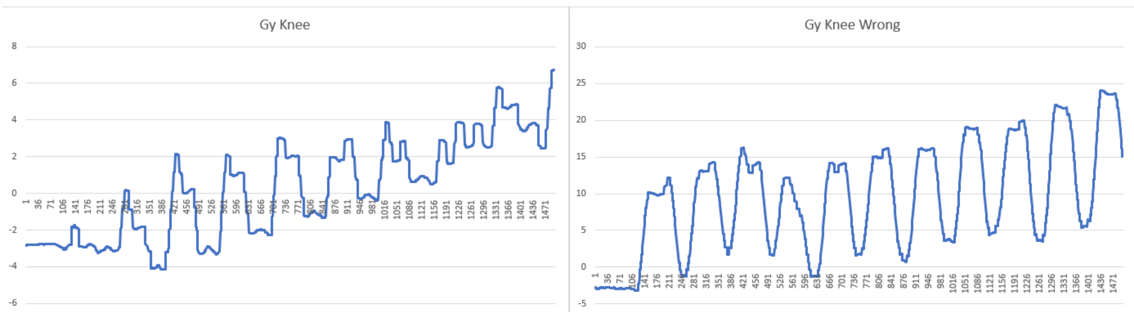


Figure 22: Dataset of Gy on the knee.

6.4 Kinds of feedback

The wearable measures a number of parameters making it possible to provide feedback on different aspects of the squat. In this section it is described when, how and where feedback is given.

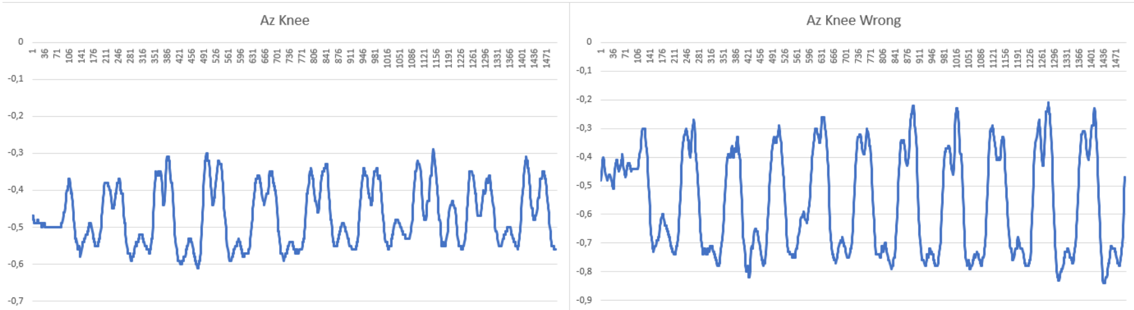


Figure 23: Dataset of Az on the knee.

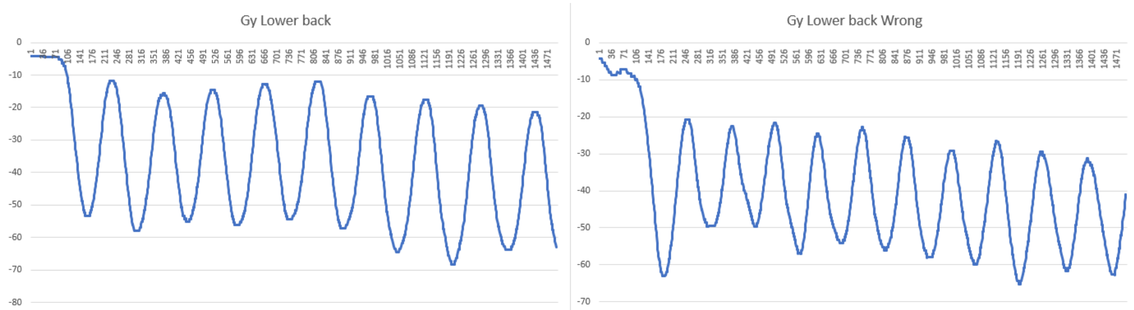


Figure 24: Dataset of Gy on the lower back.

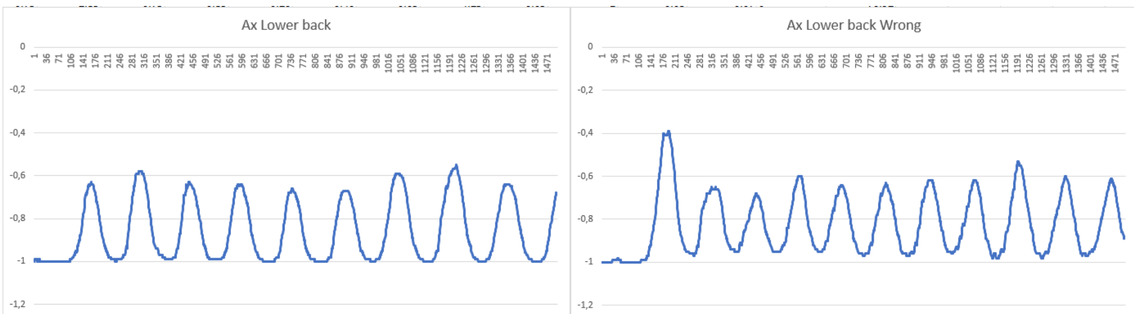


Figure 25: Dataset of Ax on the lower back.

6.4.1 Knee

There are three types of feedback that can be given at the knee: 1. when the knee go over the toes i.e., the knee bends too much. Then directional feedback towards the body will be given. This means, as the direction suggests that the user should bring his knees inward. 2. when the knees stay put and are not pushed outwards, in this situation directional feedback will be given outwards, which suggests that the knees should move more outwards. 2. the knees move before the hips, if this happens feedback will be given together with the vibration motors on the lower back. First, one vibration motor on the lower back will vibrate and closely after a vibration motor on the knee will vibrate to indicate that the hips should be moved before the knees.

6.4.2 Lower back

The lower back only allows for two types of feedback. 1. feedback given together with the vibration motors on the knee as described in section 6.4.1. 2. feedback regarding the angle made by the backbone, when the backbone is not hollow the vibration motor will quickly buzz two times to indicate a focus on the back bone.

6.5 Wearable

The sensors and vibration motors are integrated into a wearable, consisting of a band around the knee and a band around the waist. The band around the knee is elastic and therefore fits most people. The sensors and vibration motors are sown into the wearable to ensure correct placement. The waist band can be adjusted to every size using Velcro tape. The sensor and vibration motor are sown into the back and an extra bag is sown onto the band to hold the micro controller. Pictures of how the band is worn are given in figures 26, 27 and 28.

Figure 26: How the wearable is worn standing upright.

Figure 27: How the wearable is worn standing side.

Figure 28: How the wearable is worn in squat position.

7 Evaluation

The evaluation of the wearable will be discussed in this chapter. The functionalities of the wearable has been tested by users. The participants in the research provide feedback that is used to evaluate the wearable based on the requirements. The testing is done by inviting 6 participants to try the wearable and asking them to fill in a questionnaire about their experiences.

The user-test focused on intuitivity of the wearable, understandability of the feedback, restrictions posed by the wearable and possibilities of the wearable. The exact setup of the research as well as the questionnaire and corresponding consent form and brochure can be found in appendices C.1, C.2 and C.3.

7.1 Participants

For the user-test 6 participant were recruited. All participants are adults that are capable of giving consent. The user test has a very low chance of causing injury, to limit the possibility even further participants should preferably have no knee or back injury, are below 50 and sport at least once every two weeks. A practical measure that will be taken to prevent injury is that participants will not be asked to do a weighted squat or do a squat deeper than 90°. The participants will also be granted at least 3 minutes to recover between the three different sets and will be notified that if they think continuing would be a risk that they can stop. When the temperature is higher than 20°C the participant is offered a glass of water.

7.2 COVID-19

The study described in this thesis was carried out during a worldwide pandemic called COVID-19. This means that tests will, where possible, be conducted with people that are already in face-to-face contact with the researcher. Face-to-face contacts will be either family or roommates to restrict the possible spreading of COVID-19.

To further limit the spreading of COVID-19 the equipment will be cleaned after each user test and only one participant will conduct the research at any time. In the possible case that is deemed necessary to test with a close contact without face-to-face contact with the user a COVID-19 protocol has been created. This protocol can be found in appendix C.3.

7.3 Data collection

Three different types of data are collected during the user tests. All data is made anonymous and stored according to GDPR guidelines until two months after finishing this thesis.

Participants are asked to fill in two questionnaires, a pre- and a post-test questionnaire. The answers given in this questionnaire are stored and used for evaluating the wearable. A second type of data is collected from the sensors, during the test participants are asked to perform 3 sets of 15 squats. The data generated by performing these squats is stored by the researcher for analytical purposes. The last type of collected data are notes written by the researcher, during the sets of squats about the posture of the user; this is done to be able to combine sensor data with visual data to enable better evaluation.

7.4 Procedure

The study counts 6 different phases. Each of these phases and their purpose will be elaborated in this section.

The first phase is about creating a baseline, as established in section 6.3 it is impossible to find universal thresholds. To counter this a participant will be asked to perform 5 squats while they focus on the execution. This will allow the researcher to individualize the wearable by setting relevant thresholds for that user. In a later design this will be done automatically but for the user-tests this will be done manually.

The second phase serves to discover the proficiency level of the user. Completion of a questionnaire will provide information about how frequent the participant does sports, whether they had squat training etc. The questionnaire will give insight into the experience of the participant which can be used for the analysis.

The third, fourth and fifth phase each exist of 1 set of 15 squats. The user already got an explanation on how to perform a proper squat in the first phase. Phase three allows the user to check the execution of the squat. Between the third and fourth phase the researcher will provide the participant with feedback on how to improve posture. The fourth phase will therefore provide a much neater squat. In the fifth phase participants are asked to deliberately perform the squat incorrectly. There are two possibilities to perform the squat incorrectly without increasing the chance of injuries. The first one is that participants deliberately bend the knees too far, a second is that the user first moves the knee and then the hip. Each participant will be given one of these forms to perform during the fifth phase. This will provide more insight into the data and the understanding of the feedback.

The sixth and final phase is a post-questionnaire that focuses on the experience of the user with the wearable: was the feedback understandable and did the wearable restrict the participant are two focal questions in this questionnaire.

7.5 Results

The results of the user tests will be discussed in this section. During the user tests three different types of data have been collected: 1. answers to a questionnaire 2. measurement data of the IMUs 3.

observations.

7.5.1 Questionnaire

The pre- and post-test questionnaire will be discussed in three separate parts. First, the experience prior to the test with squats and wearables will be discussed, followed by the answers to the closed questions of the questionnaire. Finally, the final remarks and improvements suggested by the participants will be discussed.

Prior experiences Generally, all the participants regularly performed the squat with either their personal trainer or physiotherapist, or at football practices, home workouts or the gym. Surprisingly only one of the participants felt like he had proper training. The other participants all stated that they had little to no experience in how the squat should be performed.

Closed questions In total there were 8 closed questions. All are on a 1 to 5 likert scale; 1 represents a not .... at all or a disagree and 5 represents very ..... or agree.

The wearable was comfortable to wear.

All participants answered that the wearable was comfortable to wear. The average is 4 (N= 6, SD= 0).

The feedback was understandable.

This question had more varied results: some stated that the feedback was understandable and others stated that it was a bit vague, the average is 3.16 (N= 6, SD= 0.75).

The vibration motors were felt clearly.

The question whether the vibration motors were felt, clearly needs some remarks, the vibration motor on the back of one of the participants broke and one vibration motor on the knee of the other participants did not work. Even taking this into account there still is a large difference between the answers, with an average score of 3.33 (N= 6, SD= 1.03).

The vibration was too harsh.

The answers to this question were clear, most of the participants answered that it was soft or too soft. From the observations it can be noted that this was especially the case with the vibration motor on the lower back. The average is 2.33 (N= 6, SD= 1.2)

The wearable was easy to turn on.

When creating the questionnaire it was set out to include such a button but due to time constrains it was not achievable to include such a button.

The wearable was intuitive to use.

The overall experience of the participants was that the wearable was intuitive to use, with an average score of 4.33 (N= 6, SD= 0.81).

The wearable hindered me during the squat.

The wearable neither hindered or restricted the user during their squat; this is supported by the observations as no physical limitation of the wearable was observed. The average is 1.67 (N= 6, SD= 0.81).

I will be more prone to use the wearable if it had more functionalities.

All except one answered that they would be more likely to use the wearable if it had more functionalities. The average is 3.83 (N= 6, SD= 0.98).

Final remarks The overall experience was good. Four out of six participants stated that they would use the wearable after further development. Some statements by the participants to describe the overall experience are: very interesting, good in usage, worked well and very good idea but needs some tweaking. Another important comment made by two of the participants is that the wearable would work well for physiotherapists. One of the two (who is studying to become a physiotherapist) states that the most difficult part for a physiotherapist is to check whether their clients perform their exercises at home and even more importantly whether they perform them correctly. The designed wearable could be a solution to rate the execution and give the physiotherapist information on how often the exercise is performed. All the participant gave good recommendation to improve the wearable. Those recommendations are listed below:

- Confirmation that a squat is performed correctly.
- Better vibrations at the knee
- Making a full interface, so it can be customized.
- Make the wearable easier to put on.

The participants were asked to mention functionalities that could be added to the wearable to make it a better product. These functionalities are listed below:

- Add activities like lunges and planks.
- Add day streaks.
- Add a counter to track repetitions.

- Add stimulation to keep pushing.
- Add a voice that provides feedback if the squat is done correctly.
- Add a sensor that measures when the knees bend towards eachother*
- Add a visual explanation of how a good squat is performed.

*bending the knees towards eachother is something that happens with some women. It is not a universal mistake but is something that happens regularly.

7.5.2 Data

For each participant a dataset was stored for every performed set. This resulted in 3 datasets for each participant. After the test these three individual datasets were compared to see whether the proper sets were similar and to further investigate the differences with a wrong set.

The retrieved data allow multiple observations. The first observation is that in 5 out of 6 cases it was clearly visible that both good sets were from the same person. In 5 out of 6 cases, there was also a clear difference between the good and wrong set. The most obvious difference was consistency. Good sets were very consistent while wrong sets had no consistency at all. It was also seen that for 4 out of 6 sets the peaks of the wrong set were higher than those of the good set and should thus be detectable by the code.

7.5.3 Notes

During the user tests notes were taken to obtain more information that can improve the wearable. Most notes helped to understand answers given in the questionnaire. Almost every participant had some trouble feeling the vibration motor at the back. Another statement often made was that they would guess in which way the haptic pattern on the knee moved but could not be sure, it could not be determined if this guess was correct. Participants said it was difficult to try and activate the feedback but if they skipped a squat and just stood straight it activated all possible feedback. Half of the participants could easily make the feedback go away when they started to focus again but the other half had more difficulties in making the feedback go away once it was there. Another observation was that 5 out of 6 participants were very consistent in their squat but 1 participant needed more training; the wearable could not provide improvement of his squat during the session.

7.6 Conclusion

The evaluation will be concluded by discussing whether the requirements set out in chapter 5 are met. The requirements will be categorized in the 'must have', 'should have' and 'could have' format followed by discussing whether the requirement is met.

Must have

- The wearable is able to recognize squat patterns and properly analyse those patterns to a certain extent. More development is needed to increase the accuracy of this analysis.
- The wearable is able to provide haptic feedback at the correct place,
- The sensors and actuators are integrated into a wearable.

Should have

- The wearable has an understandable feedback pattern that indicates direction. The feedback pattern is not always understandable, more development is needed to improve the pattern.
- The wearable does not constrain the user during the exercise.
- The wearable is intuitive to use.
- The wearable does not have a button that allows for easy on and off mode. Due to the limited time available in the scope of this thesis the button is not included in the design.

Could have

- The wearable is a closed system for the processed data.
- The wearable is not powered from a battery pack in the wearable. A battery pack was not necessary during the testing so no battery pack was included.

Overall the requirements are mostly met. From the 'must have' and 'should have' only the on/off button requirement is not met. Other requirements are met in basic form. Most requirements that are met do have room for improvement but the basis for this development is present. The could have requirements are not met, currently the closed data system seems met but the evaluation showed that in further development this requirement can not be met because it limits possibilities.

8 Discussion

Reviewing the questionnaires from the user tests learns that the wearable was rather unstable. The wearable worked better for some participants than for others. This may be caused by the ability of the participant to hold a very constant posture or by individual threshold settings that were not properly set. Aspects often mentioned in the questionnaire related to fine-tuning the wearable. Improvement of the analytical capabilities of the algorithm, replacing the vibration motor on the back and fine-tuning the haptic pattern on the knee are key points to fine-tune.

The necessity of improvement of the analysis by the code is also shown in the IMU data. These data showed a high level of inconsistency in the wrong sets while the good sets showed a high level of consistency. It was also seen that peaks were about the same height in the good sets whereas wrong sets did not always show peaks with a measurable difference while the inconsistency clearly showed that it was a wrong squat. A key point for this analysis are the limitations of the current algorithm, it can only detect peaks and relies on correct thresholds. The thresholds are subject to human error because they are determined by a human and the ranges are also determined by a human. The data show that peaks are not the sole identifier for a incorrect squat. These limitations were known but the evaluation showed that erasing the limitation is necessary for improvements.

Two aspects emerged from the observations made by the researcher. The first being that participants missed the conformation that they made a correct squat. No vibration was equal to a correct squat but participants still felt unsure by the lack of feedback when the squat was performed correctly. The lack of feedback was not enough to provide conformation that a squat was done correctly. It raises the question of how to notify the user that it the squat is performed correctly without overloading the user with vibrations. Another risk is that users confuse the confirmation vibration with a feedback vibration. The second aspect was that the wearable is unable to teach a good squat when a participant has no to little experience with the squat. It can only be used to correct posture, not to learn posture. A possibility would be to add a visual explanation in a mobile phone application that trains the user and uses the feedback of the wearable to give more personal feedback.

These key results show that the goal of this thesis, to create a wearable that can correct posture for a squat, is met. But further extension of the functionalities and fine-tuning is needed to make the wearable a stable and usable product. At this point the wearable requires the user to set individual thresholds for which data needs to be analyzed. This is very difficult without an expert in the algorithm. In addition, currently the wearable only measures posture of the squat while a workout often consists of multiple exercises. It can be concluded that the results show that real-time posture correction is possible using haptic feedback and IMUs but more development time is needed to develop a market ready product; such time is not available in the scope of this thesis. Chapter 10 which should be focal points of such developments.

Misunderstanding the given feedback can be caused by several aspects: intensity, timing and focus. If the intensity is the problem the voltage going through the vibration motors can be increased which will increase the frequency and thus the intensity. If the vibration motors are timed incorrect the user will have difficulty identifying the direction, this can be improved by trying different timing combinations. For this it needs to be taken into account that it needs to be detectable while squatting. That feedback is misunderstood might relate to focus, the main focus is squatting and not recognizing patterns, the used patterns are based on research [17] that is done with people whose focus was to recognize the patterns. Having to focus on multiple aspects probably has a higher influence on users than initially expected. This can cause that the intensity is too low for this situation and that the timing needs to be different for this situation.

One implication concluded by the reflection of the results is that the analysis of the measurements needs to be extended. A good strategy for this is machine learning; during the thesis this was considered and even discussed with an expert but deemed unreachable within the scope of this thesis. Reviewing the results showed the importance of adding machine learning. Machine learning makes it possible to detect the inconsistency in the wrong squat. This inconsistency was clearly seen in the data; this means that machine learning would be able to detect a wrong squat with much more precision than peak detection could.

Another implication shown by the results is that further possibilities need to be explored. Most participants answered that they would use the product if it was available to them. Two of those participants also commented on the possibilities in physiotherapy. The wearable can help physiotherapists to track how often and how well a client performs the exercises that the physiotherapist gives. This shows a possibility to view healthcare as a possible target group. In healthcare physiotherapy and rehabilitation seem most suitable for consideration.

Overall the evaluation showed that currently the wearable is a first prototype that shows potential but also shows many points of improvement. This was also the feeling of the researcher during the evaluation, participants noticed that it was a first prototype. Which resulted in users treating it as a first prototype instead of a product. Chapter 10 will discuss how this first prototype can be developed into a product that is ready for the open market.

9 Conclusion

The goal of this bachelor thesis was to design a wearable for real-time posture correction using haptic feedback. To reach this goal the following main research question has been formulated.This question will be answered in this chapter based on the answering of the sub-research questions. The main research question is:

How to design a wearable that improves posture during the squat by providing haptic feedback?

Answering of the sub-research questions enables formulation of an answer to the main research question.

SRQ-1: Where is haptic feedback used in sport movements?

SRQ-1 is answered in sections 2.2 and 2.1. These state that haptic feedback is not widely used in sports to correct posture. Haptic feedback is used to notify the user of an event or a start but in this research no market product was found with real-time haptic feedback. It was found that researchers investigated the possibility, multiple research papers exist on using haptic feedback. Examples of this are using haptic feedback to row [37], climb [16] or navigate [18]. The haptic feedback used in these papers did not focus on correcting posture but on either timing, guidance or indication. The answer to this sub-research question is only relevant when the assumption is made that findings that apply in other sports do also apply to squatting.

SRQ-2: How can the correct execution of the exercise be measured?

To answer SRQ-2 it first needs to be established what a good squat is. This is done in section 2.1.1, it states that a good squat is defined by key body joints like knee, hips and back. Knee should not go over toes, upper leg should be parallel to the floor, hips need to move before the knees, and the chest should be proud. IMUs are introduced nn section 2.4.1 . An IMU is a sensor that measures change in angle and acceleration, when placing these IMUs on key body joints it can be measured what values correspond to a correctly performed squat. The data retrieved from the IMU are collected and analyzed by a microcontroller. How a correct squat is identified and which parameters of the IMU are relevant will be discussed under SRQ-5. Section 4.2.1, the analysis of personas, show that in the measurement injury prevention should be taken into account. The expert interview, section 2.3, showed that this is best done by making sure the user has a proud chest. A proud chest make sure that the backbone is hollow and thus puts the pressure on the quadriceps instead of the backbone itself. Chapter 2 concludes that to properly measure a squat one IMU should be placed on the lower back and another on the knee.

SRQ-3: What is a proper way to give the user understandable haptic feedback?

This thesis focuses on providing feedback with haptics. To assure that this is the correct choice section 2.1.2 investigates both, visual and auditory feedback. This section concludes that for real-time feedback with possible high-cognitive load haptic feedback is indeed the best option. Haptic feedback has a low-cognitive impact and thus is best perceived under high-cognitive load. It also is the best option to provide feedback when a user is focusing on an exercise. Section 2.1.2 also states that to provide understandable feedback it needs to be meaningful. The results in the conclusion that the feedback needs to be given at a meaningful place, i.e. the place where posture needs correction. Finally section 2.1.2 presents haptic patterns, using vibration motors to create a pattern that is understandable to the user. A pattern can be used to indicate the direction in which posture needs correction.

SRQ-4: How can data be retrieved from the sensor and properly filtered?

First, understanding of the data coming from the IMU is needed to properly retrieve it. The IMU is a three axis sensor, which means that it measures in the x, y and z direction. This is done for two parameters, the change of angle (gyroscope) and acceleration (accelerometer). In total the IMU has 6 parameters that are measured and sent to the microcontroller. The code on the microcontroller uses a library for the specific sensor to properly retrieve the data. Every loop the code asks IMU for new data, these new data are then processed in the code, as explained in section 6.2. First the data go through a moving average filter to filter out unwanted peaks. Then mathematical formulas are applied to calculate the angle from the acceleration data. The data from the gyroscope are integrated to calculate an angle as well; the angles are combined using a complementary filter to create a final angle. This angle is then used as the measurement value, the difference in angle is important to rate a squat.

SRQ-5: How is a correct squat identified using the data?

To be able to identify a good squat 18 datasets have been collected. In total these datasets came from 4 different people, 2/3 of the datasets were good squats and 1/3 of the datasets were deliberately done incorrectly. This gave insight into the difference in measurement values, as discussed in section 6.3. First the 4 relevant parameters were defined, the y direction of the gyroscope and z direction of the accelerometer for the IMU on the knee and the y direction of the gyroscope and x direction of the accelerometer for the IMU on the lower back. These parameters were then reviewed to check for similarities. It was concluded that there was no general threshold in the peaks that would work for all users. The thresholds needed to be matched to the user. In the user tests this was done by asking participants to perform 5 base squats from which thresholds for the participant could be derived. The squats were done under close supervision to assure that those squats were performed correctly. The produced thresholds were used to rate the squats performed by the participant in the rest of the session. Feedback was given when differences in peaks showed too much difference with the threshold. Either too big or too low, with the threshold.

SRQ-6: What is useful and understandable feedback?

The answer to where and how the feedback will be given is given under SRQ-3. The settings of these vibration motors are discussed in section 5.5.1 . These settings have been established by experiments. These experiments are only used to find settings for use in the user tests. These settings are tested in the user tests and as the user tests revealed needed to be changed. The frequency used for the vibration motors is 200 Hz, this is set by changing the voltage that runs through the vibration motors. The vibration motor used to indicate that a user can start doing a squat will vibrate for 0.5 second. If the feedback should indicate that the user should change posture from the back it has two fast vibration of 0.25 second just after each other. The pattern on the knee is as follows: the first vibration motor vibrates for 0.1 second, the second motor overlaps this for 0.01 second. After that the time the first one stops vibrating and the second one keeps vibrating for 0.1 second. This is repeated into the third vibration motor. The results show that these settings need to be tuned better to clearly indicate a direction going forward or a direction going backwards.

SRQ-7: Where and how are the sensors and actuators placed on the body?

This question is basically answered during the discussion of the other sub-research question. Summarized, the sensors will be placed at the lower back and the front of the knee. The actuators, the vibration motors, will also be placed at the lower back and the knee. One vibration motor will be placed at the lower back and a set of three vibration motors will be placed at the knee. Also sensors and actuators will be integrated into the wearable. This wearable consists of an elastic band around the knee and a band around the waist. The band around the knee will assure that the sensor and vibration motors are properly placed. The band around the waist will properly place the sensor and vibration motor and will also contain the microcontroller. This makes the wearable a closed system.

The answers to the sub-research questions together provide the answer to the main research question: How to design a wearable that improves posture during the squat by providing haptic feedback? The sub-research questions guide the process of which aspects are essential in the design, which aspects need to be considered when designing the wearable, and what should be improved.

In conclusion a wearable is created that rates how a squat is performed and if necessary provides meaningful feedback. The results show that the wearable has good potential to actually be used as support during workout exercises, following further development of the wearable.

10 Future work

The possibilities for further development will be discussed in this chapter. Some of the possibilities have already shortly been considered in the discussion. Those possibilities will be further elaborated in this chapter. A total of 5 possibilities and recommendations will be discussed.

The first recommendation is to fine-tune the settings and sensors. Fine-tuning the settings relates to setting the thresholds and the timing of the vibration motors. An algorithm for automatic threshold setting can be written. The differences between the peaks can be stored in an array and an average can be derived from that array. Now only an acceptable deviation from that average needs to be set, there is no need to individualize such a deviation. This makes the algorithm applicable for everybody. Research needs to be done to correctly time the vibration motors at the right intensity, current settings are difficult to recognize during squatting. A study focused on these patterns during the squat, or sports in general, needs to be done to be able to use haptic patterns as feedback. Such a research should check different settings of such haptic patterns under different cognitive loads.

A possibility to improve the wearable is to extend it for more exercises. The wearable would be a more attractive product if it could track and rate more exercises. Most logical exercises to include first are lunges, push-ups, sit-ups and planks because those form the basis for most workouts. Including new exercises requires that a user is able to switch between the exercises; this means that buttons need to be built into the wearable. In still later stages of development algorithms can be written that can recognize which exercise is performed based on the measurements. The wearable would then automatically switch making the wearable a passive product that does not require active interaction from the user during the exercises.

Machine learning has been proposed in the discussion to improve analysis of the data. Machine learning is a very good and viable solution to improve analysis. Machine learning requires lots of training data to recognize a squat and tell the difference between a good and a wrong squat. Obtaining these training data will take time and a lot of different persons that provide data. If enough data is obtained and the machine is trained in recognizing the correct posture it can be used to analyze the data. Machine learning will provide the option to not only check peaks but also values in between the peaks; it will be able to notice the inconsistency of wrong squats that peak detection is unable to detect.

An application for mobile phones is a good possibility to make the wearable more interactive for the user. Such an application increases the number of functionalities. Remote control of the wearable with an application reduces the number of physical functionalities it needs and thus simplifies the wearable itself. In addition, an application can also track progress and provide better feedback afterwards. The application can show the user how many squats have been done; it can also show previous numbers so the user can track their progress. Another functionality that can be added with the application is feedback afterwards, an example message could be: 'Your posture was very good, next time put extra focus on keeping that posture during the whole workout!'. Such a message can stimulate the user to continue using the wearable and train the user into keeping better posture.

The final recommendation relates to the target group; initially the main target group consisted of people who work out without supervision. Another possibility would be to focus on healthcare as well. As suggested in the discussion good focus areas of healthcare would be rehabilitation and physiotherapy. These areas require clients to do exercises to regain strength. Most of these exercises, especially with physiotherapy, are done at home without supervision. Extension of the wearable with exercises that physiotherapists give their clients could help clients to keep correct posture during these exercises and track whether they perform the required amount of repetitions. It will not only help the client but will also provide insight and security for the physiotherapists.

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ZW5jcnlwdGVkUXVhbGlmaWVyPUFDMDA0OU44T0VaRjAmZW5jcnlwdGVkSWQ9QTAwODI2NzYyWTNSUUgxVVJDNFFaJmVuY3J
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11 Appendices

A Appendix A

A.1 Interview guideline

Guideline-based interview

Interview number: 1

Place: Online

Date, Time: 08-04-21 8:30

Duration: 30 minutes

Introduction

Thank you very much for taking the time to do this interview with me. First of all, I will take you through the consent form.

Do you have any further questions?

Well, then I will start the recording and begin with the first question.

Topic	Key question(s)	Contingency question(s)
Getting started	Explanation about my GP and the focus of the GP. Any remarks/questions about the explanation? Do you already have things that pop up? What do you think about the idea?	
Squat	Can you take me through the doing a squat and state the important factors of the squat? Can you talk about the different versions of squats? (wide, weighted etc.)	Muscle focus of the squat, what do you train and why is it a good exercise?

Figure 29: Interview guideline for semi-structured interview part 1

Feedback	So how do you coach a trainee that performs a squat? What are your focus points of checking the squat?	If people do the squat very often do they still need feeback/coaching?
	What are typical ways of giving feedback? How would you give feedback to a user doing the squat?	What is your most used form of feedback? (saying or action)
Wearable	Do you think a wearable could help at home trainees?	Why? Or why not?
Closing	Do you have any final thoughts, add-ons, or missed opportunities that you would like to share with us?	
Closing text Now we are at the end of the interview. Would you like to add anything to the topic that seems relevant to you, that we have not yet addressed? Then I would stop the recording now. Thank you very much!		

Figure 30: Interview guideline for semi-structured interview part 2

A.2 Brochure and informed consent

Brochure and Informed consent - Online Interview

This research is by the University of Twente in the context of the graduation project posture and movement feedback in sports.

Main researchers:

Joep Blanksma with supervisors Judith Weda and Angelika Mader

Overview research

In the graduation project a device will be created that allows the user to receive instant feedback on their posture and movement when performing a squat. Instant feedback can improve the execution of the exercise and therefore improve the muscle growth and flexibility.

In order to assure correct feedback is given and the main focus of the feedback is correct, semi-structured interviews will be conducted. In this interview we will go over the most important factors for the execu-

tion of the squat. Furthermore we will discuss what the profit is of executing the squat in a correct way, what muscles are trained and if there is a difference in posture when the exercise is performed with a resistance band. Lastly we will go over common feedback given by the trainer to the sporter to improve posture, this can be spoken or physically adjusted.
Example questions:

- What is the first thing you look at when a trainee is performing a squat?
- Why should a trainee execute the squat in a correct way?
- How do you give feedback to a trainee?

Participation is voluntary. You can withdraw at any time, without giving a reason. If you decide during the interview that you do not want to participate any more, notify the interviewer. The interview will be stopped and your data will be deleted. If you decide within 48 hours after the interview that you do not want to participate anymore and want to delete your data, you can mail j.i.blanksma@student.utwente.nl with a request for deletion. Your data will be deleted.

The estimated duration of the interview will be 30 minutes.

Data

Audio footage will only be reviewed by researchers directly involved in this investigation. It will never be made public and/or shown to a third party. Al the research material will be used and stored according to the rules and guidelines of the AVG, the audio recording itself will be deleted after 48 hours to assure full anonymity. All data will be stored for 1 year. It is stored in an encrypted file on the Microsoft one drive cloud.
The data will be analyzed for research purposes. The analysis will be published in scientific articles and in 'regular' media, the results presented in any publications are fully anonymous.
The complete transcribed interviews are only accessible to the researcher directly involved in this research. Parts of the transcribed interviews can be quotes in publications, this will be in such a way that the quote is not traceable to the participant.

More info and advice by independent experts

If you have questions about this research, you can contact Joep Blanksma (j.i.blanksma@student.utwente.nl).
If you want independent advice about participating in this research, or if you want to submit a complaint. You can contact Petri de Willigen, secretary of the Ethics Committee (tel. 053-489 2085, ethicscommittee-cis@utwente.nl). This is a committee of independent expert at the university, they available for questions or complaints regarding the research.

Research: Posture and movement in sport

You will be asked to verbally give your consent for being recorded, before any recordings have started, before the online interview. If you consent, the recording will start and the statements below will be read to you, you will be asked to consent to each. Your consent will be recorded and stored separately from your interview data.

- I'm fully informed about the research. The goal of the research and the method are clear, any questions I had after reading the explanatory text were answered .
- I understand that I can withdraw from the research, without giving a reason, at any time without consequence.
- I give permission for my participation in the research and for collecting and using my data as described above.
- I give permission to record audio that will be transcribed and analyzed to design appropriate feedback mechanisms.

B Appendix B

B.1 Full code to retrieve data and control vibration motors

```
#include <Wire.h>
#include <I2Cdev.h>
#include <MPU6050_6Axis_MotionApps20.h>
#include <movingAvg.h>

int ma_N = 25;

movingAvg myAx(ma_N);
movingAvg myAy(ma_N);
movingAvg myAz(ma_N);
movingAvg myGx(ma_N);
movingAvg myGy(ma_N);
movingAvg myGz(ma_N);

movingAvg myAx_2(ma_N);
movingAvg myAy_2(ma_N);
movingAvg myAz_2(ma_N);
movingAvg myGx_2(ma_N);
movingAvg myGy_2(ma_N);
movingAvg myGz_2(ma_N);

// class default I2C address is 0x68
// specific I2C addresses may be passed as a parameter here
//AD0 low = 0x68 (default for InvenSense evaluation board)
//AD0 high = 0x69
MPU6050 mpu;
MPU6050 mpu_2(0x69); // <-- use for AD0 high


int16_t ax, ay, az;
int16_t gx, gy, gz;
int16_t ax_2, ay_2, az_2;
int16_t gx_2, gy_2, gz_2;
int low_end = -360;
int high_end = 360;
float low_acc = -4;
float high_acc = 4;
float sensitivity_acc = 4096.0;
float sensitivity_gyro = 32.8;
long timer = 0;
```

```
float angle_gyro[3];
float angle_gyro_2[3];
float angle[3];
float angle_2[3];
float angle_gyro_prev[3];
float angle_gyro_prev_2[3];
float acc_2[3];
float acc[3];
int threshold = 5;
int n = 0;
boolean toggle0 = false;
boolean toggle1 = false;
boolean toggle2 = false;
boolean toggle_f = true;
boolean toggle1_f = true;
boolean toggle2_f = true;
boolean toggle3_f = true;
boolean toggle4_f = true;
boolean toggle5_f = true;
boolean toggle6_f = false;
boolean toggle7_f = true;
boolean toggle_b = true;
boolean toggle1_b = true;
boolean toggle2_b = true;
boolean toggle3_b = true;
boolean toggle4_b = true;
boolean toggle5_b = true;
boolean toggle6_b = false;
boolean toggle7_b = true;
boolean toggle_back = true;
boolean toggle1_back = true;
boolean toggle2_back = true;
boolean toggle3_back = true;
boolean toggle6_back = false;
boolean toggle7_back = true;
boolean toggle_bk = true;
boolean toggle1_bk = true;
boolean toggle2_bk = true;
boolean toggle3_bk = true;
boolean toggle6_bk = false;
boolean toggle7_bk = true;
int threshold_python = 0;
int vibroPin1 = 11;
int vibroPin2 = 9;
```

```
int vibroPin3 = 10;
int vibroPin_back = 3;
int vibPower = 153;
int cycles = 0;
int cycles_vibrate = 0;
float max_peak_value[4];
float min_peak_value[4];
float normal_value[4];
float saved_cycle[2];
float final_cycle[2];
int gy_filtered = 0;
int gy_filtered_2 = 0;
//float ax_filtered_2 = 0;
//float az_filtered = 0;
int timing_1 = 0;
int timing_2 = 0;
int timing_3 = 0;
int timing_4 = 0;
int timing_5 = 0;
int timing_1_b = 0;
int timing_2_b = 0;
int timing_3_b = 0;
int timing_4_b = 0;
int timing_5_b = 0;
int timing_1_back = 0;
int timing_2_back = 0;
int timing_3_back = 0;
int timing_1_bk = 0;
int timing_2_bk = 0;
int timing_3_bk = 0;


//These thresholds are individual and will be altered based on individual squats.
float threshold_gy_max = 9; // + 1.5
float threshold_gy_min = 5; // -1.5
float threshold_gy_max_2 = 27; //+1.5
float threshold_gy_min_2 = 18; //-1.5
float threshold_az_max = -0.25; //+0.1
float threshold_az_min = -0.4; //-0.1
float threshold_cycles = 60;

void setup()
{
  Wire.begin();
```

```
Serial.begin(115200);
Serial.println("Initialize MPU");
mpu.initialize();
mpu_2.initialize();
mpu.setFullScaleAccelRange(2);
mpu.setFullScaleGyroRange(2);
mpu_2.setFullScaleAccelRange(2);
mpu_2.setFullScaleGyroRange(2);
Serial.println(mpu.testConnection() ? "Connected" : "Connection failed");
Serial.println(mpu.getFullScaleAccelRange());
cli();
//set timer0 interrupt at 100Hz to send data
TCCR0A = 0;// set entire TCCR0A register to 0
TCCR0B = 0;// same for TCCR0B
TCNT0  = 0;//initialize counter value to 0
// set compare match register for 2khz increments
OCR0A = 155.25;// = (16*10^6) / (2000*64) - 1 (must be <256)
// turn on CTC mode
TCCR0A |= (1 << WGM01);
// Set CS01 and CS00 bits for 64 prescaler
TCCR0B |= (1 << CS02) | (1 << CS00);
// enable timer compare interrupt
TIMSK0 |= (1 << OCIE0A);

//  //set timer1 interrupt at 0.25Hz to send signal to squat
//  TCCR1A = 0;// set entire TCCR1A register to 0
//  TCCR1B = 0;// same for TCCR1B
//  TCNT1  = 0;//initialize counter value to 0
//  // set compare match register for 1hz increments
//  OCR1A = 62499;// = (16*10^6) / (1*1024) - 1 (must be <65536)
//  // turn on CTC mode
//  TCCR1B |= (1 << WGM12);
//  // Set CS10 and CS12 bits for 1024 prescaler
//  TCCR1B |= (1 << CS12) | (1 << CS10);
//  // enable timer compare interrupt
//  TIMSK1 |= (1 << OCIE1A);
sei();
myAx.begin();
myAy.begin();
myAz.begin();
myGx.begin();
myGy.begin();
myGz.begin();
myAx_2.begin();
```

```
  myAy_2.begin();
  myAz_2.begin();
  myGx_2.begin();
  myGy_2.begin();
  myGz_2.begin();
  pinMode(vibroPin1, OUTPUT);  // sets the pin as output
  pinMode(vibroPin2, OUTPUT);
  pinMode(vibroPin3, OUTPUT);
  pinMode(vibroPin_back, OUTPUT);
}

void loop()
{
  if (toggle1 == false) {
    max_peak_value[0] = -2.6;
    min_peak_value[0] = -2.6;
    max_peak_value[1] = -0.42;
    min_peak_value[1] = -0.42;
    max_peak_value[2] = -15;
    min_peak_value[2] = -15;
    max_peak_value[3] = -0.8;
    min_peak_value[3] = -0.8;
    toggle1 = true;
  }
  mpu.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);
  mpu_2.getMotion6(&ax_2, &ay_2, &az_2, &gx_2, &gy_2, &gz_2);

  int sensorMovingAvg_acc_x = myAx.reading(ax);
  float ax_filtered = myAx.getAvg() / sensitivity_acc;

  int sensorMovingAvg_acc_y = myAy.reading(ay);
  float ay_filtered = myAy.getAvg() / sensitivity_acc;

  int sensorMovingAvg_acc_z = myAz.reading(az);
  float az_filtered = myAz.getAvg() / sensitivity_acc;

  int sensorMovingAvg_gyro_x = myGx.reading(gx);
  int gx_filtered = myGx.getAvg() / sensitivity_gyro;

  int sensorMovingAvg_gyro_y = myGy.reading(gy);
  gy_filtered = myGy.getAvg() / sensitivity_gyro;

  int sensorMovingAvg_gyro_z = myGz.reading(gz);
  int gz_filtered = myGz.getAvg() / sensitivity_gyro;
```

```

int sensorMovingAvg_acc_x_2 = myAx_2.reading(ax_2);
float ax_filtered_2 = myAx_2.getAvg() / sensitivity_acc;

int sensorMovingAvg_acc_y_2 = myAy_2.reading(ay_2);
float ay_filtered_2 = myAy_2.getAvg() / sensitivity_acc;

int sensorMovingAvg_acc_z_2 = myAz_2.reading(az_2);
float az_filtered_2 = myAz_2.getAvg() / sensitivity_acc;

int sensorMovingAvg_gyro_x_2 = myGx_2.reading(gx_2);
int gx_filtered_2 = myGx_2.getAvg() / sensitivity_gyro;

int sensorMovingAvg_gyro_y_2 = myGy_2.reading(gy_2);
gy_filtered_2 = myGy_2.getAvg() / sensitivity_gyro;

int sensorMovingAvg_gyro_z_2 = myGz_2.reading(gz_2);
int gz_filtered_2 = myGz_2.getAvg() / sensitivity_gyro;

if (gx_filtered < threshold && gx_filtered > -threshold) {
  gx_filtered = 0;
}
if (gy_filtered < threshold && gy_filtered > -threshold) {
  gy_filtered = 0;
}
if (gz_filtered < threshold && gz_filtered > -threshold) {
  gz_filtered = 0;
}
if (gx_filtered_2 < threshold && gx_filtered_2 > -threshold) {
  gx_filtered_2 = 0;
}
if (gy_filtered_2 < threshold && gy_filtered_2 > -threshold) {
  gy_filtered_2 = 0;
}
if (gz_filtered_2 < threshold && gz_filtered_2 > -threshold) {
  gz_filtered_2 = 0;
}

calculate_angle(ax_filtered, ay_filtered, az_filtered, gx_filtered, gy_filtered,
  gz_filtered, 1);
calculate_acc(ax_filtered, ay_filtered, az_filtered, 1);
calculate_angle(ax_filtered_2, ay_filtered_2, az_filtered_2, gx_filtered_2,
  gy_filtered_2, gz_filtered_2, 2);
calculate_acc(ax_filtered_2, ay_filtered_2, az_filtered_2, 2);
```

```
  //vibrate_back();
}

float complementary_filter(int gyrData, int accelData) {
  float angle = (0.95 * (gyrData)) + (0.05 * (accelData));
  return angle;
}

float accel_data(float a1, float a2, float a3) {
  float angle_acc_rad = atan(a2 / (sqrt(sq(a1) + sq(a3))));
  float angle_acc_deg = (180 * angle_acc_rad) / PI;
  return angle_acc_deg;
}

float gyro_data(float gyr_data, float prev_angle) {
  float angle_gyro = prev_angle + (gyr_data * 0.01);
  return angle_gyro;
}

void calculate_angle(float ax, float ay, float az, float gx, float gy, float gz, int
    identifier) {
  float angle_acc_x = accel_data(ax, ay, az);
  float angle_acc_y = accel_data(ay, ax, az);
  float angle_acc_z = accel_data(az, ay, ax);
  if (identifier == 1) {
    angle_gyro[0] = gyro_data(gx, angle_gyro_prev[0]);
    angle_gyro[1] = gyro_data(gy, angle_gyro_prev[1]);
    angle_gyro[2] = gyro_data(gz, angle_gyro_prev[2]);
    angle_gyro_prev[0] = angle_gyro[0];
    angle_gyro_prev[1] = angle_gyro[1];
    angle_gyro_prev[2] = angle_gyro[2];
    angle[0] = complementary_filter(angle_gyro[0], angle_acc_x);
    angle[1] = complementary_filter(angle_gyro[1], angle_acc_y);
    angle[2] = complementary_filter(angle_gyro[2], angle_acc_z);
  } else if (identifier == 2) {
    angle_gyro_2[0] = gyro_data(gx, angle_gyro_prev_2[0]);
    angle_gyro_2[1] = gyro_data(gy, angle_gyro_prev_2[1]);
    angle_gyro_2[2] = gyro_data(gz, angle_gyro_prev_2[2]);
    angle_gyro_prev_2[0] = angle_gyro_2[0];
    angle_gyro_prev_2[1] = angle_gyro_2[1];
    angle_gyro_prev_2[2] = angle_gyro_2[2];
    angle_2[0] = complementary_filter(angle_gyro_2[0], angle_acc_x);
    angle_2[1] = complementary_filter(angle_gyro_2[1], angle_acc_y);
    angle_2[2] = complementary_filter(angle_gyro_2[2], angle_acc_z);
```

```
  }

}

void calculate_acc(float a1, float a2, float a3, int identifier) {
  float R = sqrt(sq(a1) + sq(a2) + sq(a3));
  float Rx = float(a1) / (float)R;
  float Ry = float(a2) / (float)R;
  float Rz = float(a3) / (float)R;
  if (identifier == 1) {
    acc[0] = Rx;
    acc[1] = Ry;
    acc[2] = Rz;
  } else if (identifier == 2) {
    acc_2[0] = Rx;
    acc_2[1] = Ry;
    acc_2[2] = Rz;
  }
}

void vibrate_back() {
  analogWrite(vibroPin_back, 200);
  toggle0 = true;
}


ISR(TIMER0_COMPA_vect) { //timer0 interrupt 100Hz
  Serial.print(angle[1]); Serial.print(";");
  Serial.print(acc[2]); Serial.print(";");
  Serial.print(angle_2[1]); Serial.print(";");
  Serial.print(acc_2[0]); Serial.print(";");
  Serial.print(max_peak_value[0]); Serial.print(";");
  Serial.print(min_peak_value[0]); Serial.print(";");
  Serial.print(max_peak_value[1]); Serial.print(";");
  Serial.print(min_peak_value[1]); Serial.print(";");
  Serial.print(max_peak_value[2]); Serial.print(";");
  Serial.print(min_peak_value[2]); Serial.print(";");
  Serial.print(max_peak_value[3]); Serial.print(";");
  Serial.print(min_peak_value[3]); Serial.print(";");
  Serial.print(saved_cycle[0]); Serial.print(";");
  Serial.print(saved_cycle[1]); Serial.print(";");
  Serial.print(millis() / float(1000.0)); Serial.print(";");
  Serial.println(cycles);
  if (toggle2 == true) {
```

```
    peak_detection(angle[1], 0);
    peak_detection(acc[2], 1);
    peak_detection(angle_2[1], 2);
    peak_detection(acc_2[0], 3);
  }
  if (cycles == 400) {
    vibrate_back();
    cycles = 0;
    toggle2 = true;
  }
  if (toggle0 == true) {
    cycles_vibrate += 1;
  }
  if (cycles_vibrate == 50) {
    analogWrite(vibroPin_back, 0);
    toggle0 = false;
    cycles_vibrate = 0;
  }
  vibration();
  cycles += 1;
}

void peak_detection(float value, int identifier) {
  if (identifier == 0) {
    if (value > max_peak_value[0]) {
      max_peak_value[0] = value;
    } else if (value < min_peak_value[0]) {
      min_peak_value[0] = value;
    }
    if (cycles == 400) {
      //provide min and max peak to void that compares
      check_up(max_peak_value[0], min_peak_value[0], 0);
      float average_0 = (max_peak_value[0] + min_peak_value[0]) * 0.5;
      max_peak_value[0] = average_0;
      min_peak_value[0] = average_0;
    }
  }
  if (identifier == 1) {
    if (value > max_peak_value[1]) {
      max_peak_value[1] = value;
      saved_cycle[0] = cycles;
    } else if (value < min_peak_value[1]) {
      min_peak_value[1] = value;
    }
```

```
    if (cycles == 400) {
      //provide min and max peak and cycle to void that compares
      check_up(max_peak_value[1], min_peak_value[1], 2);
      float average_1 = (max_peak_value[1] + min_peak_value[1]) * 0.5;
      max_peak_value[1] = average_1;
      min_peak_value[1] = average_1;
    }
  }
  if (identifier == 2) {
    if (value > max_peak_value[2]) {
      max_peak_value[2] = value;
    } else if (value < min_peak_value[2]) {
      min_peak_value[2] = value;
    }
    if (cycles == 400) {
      //provide min and max peak to void that compares
      check_up(max_peak_value[2], min_peak_value[2], 1);
      float average_2 = (max_peak_value[2] + min_peak_value[2]) * 0.5;
      max_peak_value[2] = average_2;
      min_peak_value[2] = average_2;
    }
  }
  if (identifier == 3) {
    if (value > max_peak_value[3]) {
      max_peak_value[3] = value;
      saved_cycle[1] = cycles;
    } else if (value < min_peak_value[3]) {
      min_peak_value[3] = value;
    }
    if (cycles == 400) {
      //provide min and max peak and cycles to void that compares
      check_up(0, 0, 3);
      float average_3 = (max_peak_value[3] + min_peak_value[3]) * 0.5;
      max_peak_value[3] = average_3;
      min_peak_value[3] = average_3;
    }
  }
}
void check_up(float maximum, float minimum, int identifier) {
  if (maximum < 0){
    maximum = maximum * -1.0;
  }
  if (minimum < 0){
    minimum = minimum * -1.0;
```

```
}
if (identifier == 0) {
  float difference = maximum - minimum;
  if (difference > threshold_gy_max) {
    //run forward thing knee
    toggle_f = false;
    //Serial.print("forward knee on gyro"); Serial.print("\t"); Serial.println(
  difference);
  } else if (difference < threshold_gy_min) {
    //run backwards thing knee
    //Serial.print("Backward knee on gyro"); Serial.print("\t"); Serial.println(
  difference);
    toggle_b = false;
  }
}
if (identifier == 1) {
  float difference = minimum - maximum;
  if (difference > threshold_gy_max_2) {
    //run two short pulses back
    toggle_back = false;
    //Serial.print("back max on gyro"); Serial.print("\t"); Serial.println(difference)
  ;
  } else if (difference < threshold_gy_min_2) {
    //run two short pulses back
    toggle_back = false;
    //Serial.print("back min on gyro"); Serial.print("\t"); Serial.println(difference)
  ;
  }
}
if (identifier == 2) {
  float difference = maximum - minimum;
  if (difference > threshold_az_max) {
    //run forward thing
    toggle_f = false;
    //Serial.print("forward knee on acc"); Serial.print("\t"); Serial.println(
  difference);
  } else if (difference < threshold_az_min) {
    //run backwards thing
    toggle_b = false;
    //Serial.print("backward knee on acc"); Serial.print("\t"); Serial.println(
  difference);
  }
}
if (identifier == 3) {
```

```
    float difference = abs(saved_cycle[1] - saved_cycle[0]);
    if (difference < threshold_cycles) {
      //run knee back script.
      //toggle_bk = false;
      //Serial.print("cycles"); Serial.print("\t"); Serial.println(difference);
    }
  }
}

void vibration() {
  forward_vibration();
  backward_vibration();
  back_vibration();
  knee_back_vibration();
}

void forward_vibration() {
  if (toggle_f == false) {
    toggle_f = true;
    toggle6_f = true;
    timing_1 = cycles + 110;
    timing_2 = cycles + 111;
    timing_3 = cycles + 120;
    timing_4 = cycles + 121;
    timing_5 = cycles + 130;
  }
  if (toggle6_f == true && cycles > 100) {
    if (toggle7_f == true) {
      analogWrite(vibroPin1, vibPower);
      toggle7_f = false;
    }
    if (cycles > timing_1 && toggle1_f == true) {
      analogWrite(vibroPin2, vibPower);
      toggle1_f = false;
    } else if ( cycles > timing_2 && toggle2_f == true) {
      analogWrite(vibroPin1, 0);
      toggle2_f = false;
    } else if ( cycles > timing_3 && toggle3_f == true) {
      analogWrite(vibroPin3, vibPower);
      toggle3_f = false;
    } else if ( cycles > timing_4 && toggle4_f == true) {
      analogWrite(vibroPin2, 0);
      toggle4_f = false;
    } else if ( cycles > timing_5 && toggle5_f == true) {
```

```
      analogWrite(vibroPin3, 0);
      toggle5_f = false;
      toggle6_f = false;
    }
    if (toggle6_f == false) {
      toggle1_f = true;
      toggle2_f = true;
      toggle3_f = true;
      toggle4_f = true;
      toggle5_f = true;
      toggle7_f = true;
    }
  }
}

void backward_vibration() {
  if (toggle_b == false) {
    toggle_b = true;
    toggle6_b = true;
    timing_1_b = cycles + 110;
    timing_2_b = cycles + 111;
    timing_3_b = cycles + 120;
    timing_4_b = cycles + 121;
    timing_5_b = cycles + 130;
  }
  if (toggle6_b == true && cycles > 100) {
    if (toggle7_b == true) {
      analogWrite(vibroPin3, vibPower);
      toggle7_b = false;
    }
    if (cycles > timing_1_b && toggle1_b == true) {
      analogWrite(vibroPin2, vibPower);
      toggle1_b = false;
    } else if ( cycles > timing_2_b && toggle2_b == true) {
      analogWrite(vibroPin3, 0);
      toggle2_b = false;
    } else if ( cycles > timing_3_b && toggle3_b == true) {
      analogWrite(vibroPin1, vibPower);
      toggle3_b = false;
    } else if ( cycles > timing_4_b && toggle4_b == true) {
      analogWrite(vibroPin2, 0);
      toggle4_b = false;
    } else if ( cycles > timing_5_b && toggle5_b == true) {
      analogWrite(vibroPin1, 0);
```

```
      toggle5_b = false;
      toggle6_b = false;
    }
    if (toggle6_b == false) {
      toggle1_b = true;
      toggle2_b = true;
      toggle3_b = true;
      toggle4_b = true;
      toggle5_b = true;
      toggle7_b = true;
    }
  }
}

void back_vibration() {
  if (toggle_back == false) {
    toggle_back = true;
    toggle6_back = true;
    timing_1_back = cycles + 175;
    timing_2_back = cycles + 185;
    timing_3_back = cycles + 210;
  }
  if (toggle6_back == true && cycles > 150) {
    if (toggle7_back == true) {
      analogWrite(vibroPin_back, vibPower);
      toggle7_back = false;
    }
    if (cycles > timing_1_back && toggle1_back == true) {
      analogWrite(vibroPin_back, 0);
      toggle1_back = false;
    } else if ( cycles > timing_2_back && toggle2_back == true) {
      analogWrite(vibroPin_back, vibPower);
      toggle2_back = false;
    } else if ( cycles > timing_3_back && toggle3_back == true) {
      analogWrite(vibroPin_back, 0);
      toggle3_back = false;
      toggle6_back = false;
    }
    if (toggle6_back == false) {
      toggle1_back = true;
      toggle2_back = true;
      toggle3_back = true;
      toggle7_back = true;
    }
```

```
  }
}

void knee_back_vibration() {
  if (toggle_bk == false) {
    toggle_bk = true;
    toggle6_bk = true;
    timing_1_bk = cycles + 275;
    timing_2_bk = cycles + 285;
    timing_3_bk = cycles + 310;
  }
  if (toggle6_bk == true && cycles > 250) {
    if (toggle7_bk == true) {
      analogWrite(vibroPin_back, vibPower);
      toggle7_bk = false;
    }
    if (cycles > timing_1_bk && toggle1_bk == true) {
      analogWrite(vibroPin_back, 0);
      toggle1_bk = false;
    } else if ( cycles > timing_2_bk && toggle2_bk == true) {
      analogWrite(vibroPin1, vibPower);
      toggle2_bk = false;
    } else if ( cycles > timing_3_bk && toggle3_bk == true) {
      analogWrite(vibroPin1, 0);
      toggle3_bk = false;
      toggle6_bk = false;
    }
    if (toggle6_bk == false) {
      toggle1_bk = true;
      toggle2_bk = true;
      toggle3_bk = true;
      toggle7_bk = true;
    }
  }
}
```

C Appendix C

C.1 Setup of the experiment

Setup experiment:

(a) Perform 5 baseline squats

(b) Pre-Questionnaire

(c) Perform 15 squats on the beep you feel at your back, if you feel the beep you can start a squat.

(d) I will explain how you execute a proper squat then perform 15 squats on the beep you feel at your back.

(e) You will be asked to perform squats without correct form, you will be assigned one of two things, move your knees to far forward or first move your knees and tehn your hips.

(f) Post-Questionnaire

Make notes of how the participants performs the squat.

C.2 Pre- and post-Questionnairre

Testing wearable to improve posture during squats.

Thank you for helping me test my wearable

* Required

Do you have any current knee or back injuries? If you answer yes please notify the researcher. *

- ○ Yes
- ○ No

Do you by any means not feel able to perform a squat? If you answer yes please notify the researcher. *

- ○ Yes
- ○ No

Please explain your experience with squatting? Online, in the gym, little experience, professional etc. *

Your answer

Please explain your experience with wearables? (smartwatches or other device to improve or track while exercising) *

Your answer

Have you ever had any training or explanation about the squat, if so please explain what you remember. *

Your answer

Next

Testing wearable to improve posture during squats.

Experiment

Now we will perform some squats. The researcher will explain the proceedings.

Back Next

Testing wearable to improve posture during squats.

Post-Questionnaires

The wearable was comfortable to wear.

	1	2	3	4	5	
Not comfortable at all	○	○	○	○	○	Very comfortable

The feedback was understandable.

	1	2	3	4	5	
Not understandable	○	○	○	○	○	Very clear

The vibration motors were felt clearly.

	1	2	3	4	5	
Not clear at all	○	○	○	○	○	Very clear

The vibration was too harsh.

	1	2	3	4	5	
Too soft	○	○	○	○	○	Too harsh

The wearable is easy to turn on.

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

The wearable felt intuitive to use.

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

The wearable hindered me during the squat.

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

I would use the wearable during my workout. If not please state what needs to be done to make it useable in a workout.

Your answer

I will be more prone to use the wearable if it had more functionalities.

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

What are functionalities that you would have liked to see on the wearable?

Your answer

Can you describe your overall experience with the wearable?

Your answer

Do you have any recommendations to improve the wearable?

Your answer

Back Submit

C.3 Consent form, brochure user testing and COVID-19 protocol

Group	PP nr.

Consent form

UNIVERSITY OF TWENTE.

The University of Twente and the Department of EEMCS support the practice of protecting research participants' rights. Accordingly, this project was reviewed and approved by an Institutional Ethical Board. The information in this consent form is provided so that you can decide whether you wish to participate in our study. It is important that you understand that your participation is considered voluntary. This means that even if you agree to participate you are free to withdraw from the experiment at any time, without penalty.

Contact information
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Declaration of consent (please tick each checkbox if you consent)

◯ **1.** I agree to participate in this study

◯ **2**. I have read the instructions above and understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

◯ **3**. I understand that my identifiable data is recorded for research purposes as described above, and can be stored until 2 months after finishing the thesis.

______________________________________ __________________

Name and signature participant Date

______________________________________ __________________

Name and signature researcher Date

Additional consent: contact in case of covid-19

In case that one of the participants in this research or a researcher contracts COVID-19, we will keep the contact data of all participants in this experiment. If a participant or researcher tests positive for COVID-19 and the research team is contacted by the GGD (Gemeentelijke Gezondheidsdienst or city health service) for contact research or otherwise made aware, you will be send a message. The message will state that someone in the experiment has contracted COVID-19 and will include a request for you to contact your general practitioner or local GGD. No names or identifying information will be shared. Your contact data will be stored for up to a month after the experiments have ended and will be destroyed after the time period is up. Your contact data is stored separately from your research data and cannot be connected to your research data.

Declaration of consent (please tick the checkbox if you consent)

◯ I agree for my contact data to be stored as described above.

______________________________________ __________________

Name and signature participant | Date

______________________________________ __________________

Name and signature researcher | Date

Enschede, date …..

Dear reader,

In this letter, we would like to inform you about the research that can be conducted. The experiment will take place on dd-mm-yy, in room xxx of the xxx building. In the proposed research, entitled "Designing a wearable that improves posture during a squat by providing haptic feedback", a wearable will be tested with you to test if the wearable works as it should be and if there are any improvements. This will be done by asking you to perform 3 sets of 15 squats. All three sets have a different goal, with explanation, without explanation and purposely incorrect. The order of these sets are not pre-determined and will be different for every participant. Before and after the experiment you will be asked to fill in a questionnaire. In these questionnaires you will be asked about your experience with squats and the performance of the wearable.

The aim of the research is to find if the designed wearable works according to the design standards set by the researcher.

You will wear the designed wearable, which is placed on the lower back and the knee. However you can take off the wearable at any time. The wearable is a band around your was and a band around your knee. Vibration motors are woven into the wearable to provide you with feedback. In the knee band three vibration motors are present and in the band around your waist one vibration motor is present. You can decide to stop at any point in the course of the experiment without this having any consequences for yourself and without giving any reasons. In addition, you can still decide at the end of the experiment and any time after the end of the experiment, that your data may not be included in the research after all. Other relevant aspects are that your data will be handled in a confidential manner, the anonymity of your data is guaranteed because it will not be stored with an identifier that can be linked to the participant and will never be disclosed to third parties without your permission in the consent from. All data will be treated according to GDPR guidelines, this data includes the answers to the questionnaire and the data coming from the sensors in the wearable. All the data will be deleted 2 months after finishing the thesis.

The experiment lasts for a maximum of 1 hour, but there will be breaks in between.

At the end of the entire research, you may, if you so wish, be informed about the results obtained by means of a debriefing.

Yours sincerely,

Joep Blanksma

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COVID-19 Brochure Amendment

Dear participant,

Your health and safety is our main concern, in this addition we would like to explain the changes we made to the experiment set-up and procedure to protect you and the researcher during the pandemic.

- You will be asked about your health before the start of the experiment. If you have symptoms of a cold you will not be able to participate.
- If you have any symptoms of a cold, please contact Joep Blanksma at j.i.blanksma@student.utwente.nl to cancel your appointment.
- If a researcher experiences symptoms of a cold, they will not conduct the experiment. They are replaced or you appointment will be canceled.
- Doors are opened for you so you do not have to touch door handles.
- Participants wash their hands before and after the experiment.
- The researcher washes their hands before and after every experiment.
- Participants are asked to leave their contact information separately from the research data, so that they may be contacted in the case that any of the participants or researchers test positive for COVID-19 after the study. If we are contacted by the GGD (Gemeentelijke Gezondheidsdienst or city health service) or are otherwise made aware that one of the participants or researchers tested positive, we will send a message to all participants informing them and asking them to contact their general practitioner or local GGD. This message will never contain a name or any identifiable information of the participant or researcher that contracted COVID-19 The contact information will be deleted a month after the study has ended. You will be asked for permission in a separate consent form.
- If you test positive for COVID-19 after the experiment, please contact Joep Blanksma at j.i.blanksma@student.utwente.nl
- Physical contact between the researcher and participant during the experiment is limited to correctly placing the arm of the participant in the experiment set-up.
- The participant and researcher are separated by at least 2 m distance.
- The set-up is disinfected, after each participant and at the start and end of the day.
- Sensors and vibration motors are placed directly on the skin will be cleaned for every participant.
- A max of 2 people are in the room at a given time.

We would like to remind you of your right to withdraw at any time without giving a reason. If you do not find these precautions sufficient, feel uncomfortable or are in a at risk group reconsider your participation.

If you have any questions or concerns, please contact Joep Blanksma at j.i.blanksma@student.utwente.nl . If you want independent advice about participating in this research, or if you want to submit a complaint. You can contact Petri de Willigen, secretary of the Ethics Committee (tel. 053-489 2085, ethics-comm-ewi@utwente.nl). This is a committee of independent experts at the university, they available for questions or complaints regarding the research.

Yours sincerely,

Joep Blanksma